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ABSTRACT

Designed for individualized use in an applied physics course in postsecondary vocational-technical education, this series of six learning modules is equivalent to the content of a three-credit hour class in surveying and drafting technology, architectural drafting technology, building construction technology, and civil engineering technology. Almost all the modules contain technological application in the form of laboratory experiments or as applied homework problems. Each module contains the following components: a cover page explaining the purpose and contents of the module; learning objectives; learning activities; a self-evaluation test with an answer key; and a final test based on the stated objectives. These six modules are a part of twenty-three applied physics modules which have been developed for use in several technology courses, including manufacturing engineering, machine tool and design, welding, industrial plastics, electrical, electronic service, electronic engineering, and electromechanical, automotive, and diesel technologies. All twenty-three modules are available in ERIC document CE 014 409. Instructions in the use of the modules, related notes, data sheets, tests, and answer keys are included in a separate document (CE 014 408). (BM)

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Applied Physics Modules Selected for Architectural and Civil Drafting Technologies

October 1976

U S DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

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CE 014 411

Southeast Community College--Milford Campus, Milford, Nebraska 68405

Applied Physics Module

SOUTHEAST COMMUNITY COLLEGE—Milford Campus Milford, Nebr. 68405

Module: M 2

Title: Sizing Things Up

Module Contents:
1. Measuring systems
2. Fundamental and derived units
3. Conversion of units
4. The metric system
5. Precision measurement
6. Accuracy in measurement and computations

Program: This unit has been prepared especially for students in:
1. Civil engineering technology
2. Architectural technology
3. Building construction technology

Purpose: The purpose of this module is to enable you to move forward in your chosen technology and in your physics course. The study of measurement, which is usually the first module of a physics course, is a prerequisite for most modules that follow in this couse. In order for your production (on the job) to meet necessary standards, the study of measuring systems, standards and conversion of units is an absolute requirement. With conversion to the metric system in the United States at an accelerated rate, it is necessary that you, as a construction student, be familiar with and be able to use the metric system.

Producer: Gene Waring

Date Produced: August, 1976

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STUDENT INSTRUCTIONS

Module M 2 SIZING THINGS UP

OBJECTIVES

When you have satisfactorily completed this module you will be able to:

1. Define fundamental and derived units.
2. Describe the standardization of fundamental units and give examples of at least five derived units.
3. Describe consistent measuring systems (British, mks and cgs) in terms of fundamental and derived units.
4. State the difference between an absolute and a gravitational measuring system.
5. Derive the units of a quantity, expressed in fundamental units (British, mks or cgs) when given the definition of the quantity.
6. State the conversion factors between commonly used units of time, distance, area, volume, and weight within the British measuring system.
7. State the name of, the abbreviation for, and the factor of the commonly used metric prefixes.
8. Convert a given quantity from one unit to another (British to British, metric to British, British to metric, or metric to metric) using the method of unit analysis, given a table of conversion factors.
9. State the definition of mass density and weight density.
10. State the formulas for the area and volume of commonly shaped objects (rectangles, circles and triangles - rectangular solid, cylinder and sphere).
11. Define the words: accuracy and uncertainty.
12. Round computed answers correctly to indicate the uncertainty in computations.
13. Estimate lengths and volumes of objects in metric units to at least 15%.
14. Use a balance to measure the weight or mass of various objects.
15. Use a vernier caliper to measure the length of an object to 0.1 mm or 0.01 in.
16. Use a micrometer caliper to measure the length of objects to within 0.01 mm and/or 0.001 in.

In order to satisfactorily complete this module, you must pass a test consisting of true-false, multiple choice, and problem type questions based on the objectives listed above with a grade of at least 80%.

SELF-EVALUATION TEST

Perhaps you have had previous experience with the study of measurement. You may feel that your experience will enable you to perform most of the tasks listed in the objectives section above. A self-evaluation test (or sample test) is included in this booklet (pink paper, page 5) along with an answer key. You can evaluate your previous knowledge of the subject by taking this test (under normal test conditions) before you perform any of the learning activities listed below.

The results of this test is an indication of your knowledge. If you can answer all questions correctly, you may not need additional study. However, you should proceed with the learning activities if you can't answer all questions, correctly. The answer key page (pink page 6) directs you to various learning activities.

Before you take the instructor-graded test (post-test), read the "test" section at the end of these instruction pages (white paper, page 3).

LEARNING ACTIVITIES

The following list of activities is designed to help you achieve the objectives of this module. You are not required to complete all of the activities. They are intended to supplement your previous knowledge of the subject.

If the results of your self-evaluation test indicates your knowledge of measuring systems in general is weak, do the reading. If you have trouble converting units, practice solving problems. If the metric system or the use of measuring instruments is your weakness, do the experiments. You may want to do most or all of the activities if your overall background requires it. If you wish, your instructor will recommend the learning activities you should complete.

I. Reading: The chapters, sections and page numbers are given for several textbooks. You may select your own textbook and the information sheet that is included in this booklet. As you read, keep the list of objectives handy. Write down on separate paper a list of the definitions, laws, principles, formulas, etc., that the objectives refer to. This list will be very useful as an aid to memorizing them.

A. Information Sheet. Read the information sheets included in this booklet. They are printed on green paper, (page 7). The information sheets cover subject matter that is presented only briefly or not at all in the textbooks.

B. Introductory Applied Physics, Harris, N. C., Hemmerling, E. M., McGraw-Hill, 3rd ed., 1972. Read all of chapters 2, pages 23-28.

C. Elements of Physics, Amith, A. W., Cooper, J. N., McGraw-Hill, 8th ed., 1972. Read all of chapter 1, pages 2-12.

D. Physics for Career Education, Ewen, D., Nelson, R., Schurter, N., McFadden, 1., Prentice-Hall Inc., 1st ed., 1974. Read all of chapter 1, pages 1-14.

E. Physics for Technology, Betts, J., Reston Publishing Co. Inc., 1st ed., 1976. Read all of chapter 1, pages 1-11.

F. Modern Technical Physics, Beiser, A., Cummings Publishing Co. Inc., 1st ed., 1966. Read section 1.8 in chapter 1, pages 14-16 and section 6.7 in chapter 5, pages 70-73.

II. Listening/Viewing: The following filmstrips with cassette tapes are available in the learning Resource Center (LRC). There is a brief training session given by the LRC staff to familiarize you with the projection and sound equipment (Hitachi SPR-771) and must precede the viewing of the films. Ask the LRC personnel about this training.

A. The International System of Units (SI), (QC/93/.U2x/1974). A four-part series.

1. CL-550-5 Introduction to the International System of Units
2. CL-550-7 Metric Units: Mass and its Derivatives

You need not view the two unlisted films in this series since they will be a part of other applied physics modules.

B. Understanding the Metric System, (QC/95/.I8x/1973). A four-part series.

1. C1-550-12 Measuring Volume

You need not view the three unlisted films in this series since they are introductory.

The following 35 mm film is available in the LRC. Ask the LRC personnel for a training session to familiarize you with the projector which must precede the viewing of the film.

A. The Outside Micrometer, (MP-46) L. S. Starrett Co., (1972)

III. Solving Problems: Solve the even numbered problems in the problem set in this booklet. They are printed on ivory paper. Answers are given for each problem. Solve as many of the even numbered problems as you feel are necessary to gain competence in manipulating units.

IV. Solving Problems (Optional): Solve the odd numbered problems in the problem set in this booklet. These are for additional practice if you feel it is needed.

V. Performing Laboratory Experiments: There are five experiments in this module. They will give you practice in learning metric measurements of distance, volume, mass and density. One experiment will give you practice making distance measurements with precision instruments.

Read the laboratory instruction in this booklet (on yellow paper) and pay particular attention to the cautions given. Obtain a laboratory data sheet (M-2) and the equipment from the instructor. Keep this booklet open to the instruction pages and proceed step by step with the experiment.

TEST

You may proceed with the test at any stage of your study of this module; obtain a copy of the test, answer all questions and return it to your instructor.

A grade of 80% is required for satisfactory completion of the module. A grade lower than 80% will require that you repeat the test. You must show evidence of further study before you repeat it, however. (Hand in your papers on problem solving, lab reports, etc.)

Every test you take on this module will be averaged to determine your module grade. Don't take the test until you have adequately prepared yourself to meet the requirements listed in the objectives section. Instead, go to the learning activities.

SELF-EVALUATION TEST

Module M 2 SIZING THINGS UP

Read each question carefully and decide which one of the answers is best. Notice what letter your choice is. Then, on separate paper, write the problem number followed by the letter you chose. Take the test under normal test conditions; without help from other people and without references. The answer key is on the following page.

T - F 1. The three fundamental quantities adopted for mechanics in an absolute measuring system are time, mass, and distance.

T - F 2. The prefix meaning one thousandth is mega and its abbreviation is the capital letter M.

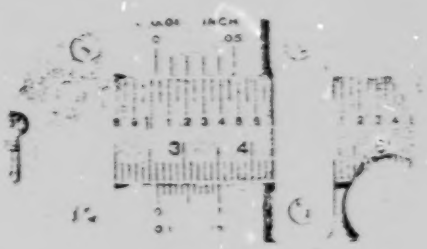
T - F 3. The term "uncertainty" generally refers to the reliability of measuring instruments.

T - F 4. A liter is about 6% larger than a quart.

T - F 5. An equivalent of 110 mi/h is 75 ft/s.

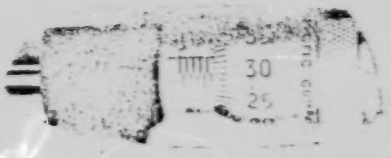
6. The density of battery acid is 10.8 lb/gal. In grams per cubic centimeter it is
   a) 13.6 c) 1.3
   b) 8.33 d) 1.0

7. Density is defined as: density = mass/volume and volume = constant x (distance)^3. The fundamental units of density in the mks measuring system is
   a) kg/m^3 c) kg/m^3
   b) kg·m^3 d) lb/ft^3



8. The reading of the vernier caliper in millimeters is
   a) 2.61 c) 2.01
   b) 2.51 d) 3.50

9. The reading of the micrometer caliper in millimeters is
   a) 4.319 c) 3.819
   b) 4.819 d) 5.319



10. How many millifarads is 37.6 μF?
    a) 37 600 000 c) 37 600
    b) 0.0000375 d) 0.0375

11. Which of the following is the largest?
    a) 2 200 milliliters c) 0.25 cubic feet
    b) 15 pints d) 500 cubic inches

12. The speed of an electric wave in a transmission line is 130 000 mi/s. Express this speed in kilometers per hour.

7

ANSWER KEY TO THE SELF-EVALUATION TEST

Module M 2 SIZING THINGS UP

Question-Answer	If you missed this question, you are directed to these learning activities
1. T	I Reading or II Listening/Viewing
2. F	II Reading or II Listening/Viewing
3. F	I Reading (Information Page)
4. T	V Performing Laboratory Experiments
5. F	III Solving Problems
6. c	III Solving Problems
7. c	III Solving Problems and I Reading (Information Page)
8. a	V Performing Laboratory Experiments
9. b	V Performing Laboratory Experiments
10. d	III Solving Problems
11. d	III Solving Problems
12. 7.53×10^8 km/h	III Solving Problems

INFORMATION SHEET

Module M 2 SIZING THINGS UP

A consistant measuring system requires that a few quantities be defined independently of all others. These few quantities are called fundamental quantities. One of the units used to measure fundamental quantities is also defined in a fundamental way, i.e., independent of other units. Three fundamental quantities and their fundamental units are required in the study of mechanics. Additional fundamental quantities and their units are required in the study of heat, optics and electricity.

There are two types of measuring systems: absolute and gravitational. Both types use time and distance as fundamental. The difference being in the choice of the third quantity. An absolute system uses mass for the third quantity; a gravitational system uses weight. The mks (meter - kilogram - second) and the cgs (centimeter-gram-second) systems of measurement, using metric units, are both absolute systems. The British system is gravitational. See table 1 for the fundamental units of these three systems.

System	Time	Distance	Mass	Weight (force)
Absolute mks	second	meter	kilogram	----------
cgs	second	centimeter	gram	----------
Gravitational British	second	foot	--------	pound

Table 1. Fundamental units of the common measuring systems.

WHY THE DIFFERENCE?

The weight of an object varies over the surface of the earth; from sea level to mountain top; from equator to poles, with local variations besides. Large variations in an object's weight occurs when it is moved to outer space. Weight depends on gravity. Thus, the choice of weight as fundamental gives rise to the name gravitational system.

The mass of an object, however, does not vary. It is the measure of the inertia of the object. The inertia depends only on the amount of matter the body contains; the number of protons, neutrons and electrons that make up the object. So the mass of an object is the same at sea level as on a mountain top and in outer space. Since mass is absolutely constant we have the name; absolute measuring system.

The concept of mass and the concept of weight are not difficult to distinguish. However, people tend to forget the difference. Actually, the confusion stems from the fact that both can be measured on the same measuring instrument. If you place equal weights on the pans of a balance scale, you have also placed equal masses on the pans. You should keep the statements of the two previous paragraphs in mind. The distinction between mass and weight will become clearer with further study of physics.

FUNDAMENTAL UNITS

Time: All three systems described in table 1 uses the second as the fundamental unit of time. The second has an exact definition, (see your textbook). Other units of time are defined for particular uses in terms of the second; 1 minute = 60 seconds, 1 hour = 3600 seconds, etc.

Distance: The meter is the fundamental unit of distance in the mks system, (see your textbook for the precise definition). The unit of distance in the cgs and British systems are legally defined in terms of the meter; 1 centimeter = 0.01 meter, 1 foot = 0.3048 meters. Other units for particular purposes are defined in terms of the fundamental units; 1 yard = 3 feet, 1 kilometer = 1000 meters, etc.

Mass: The fundamental unit of mass in the mks system is the kilogram and in the cgs system, the gram. (See your textbook for the precise definition of the kilogram; 1 gram = 0.001 kilogram.) The slug is the unit of mass in the British gravitational system; (1 slug = 14.59 kilogram). Mass is not a fundamental unit in the British system, however, it is defined in terms of weight, time and distance within that system.

Weight (Force): In the British system, weight is fundamental. The unit is the pound, defined as the weight of 0.54359237 kilograms of mass. The newton (mks) and the dyne (cgs) are derived units of weight and are defined in terms of the units of mass, time, and distance in their respective measuring systems.

DERIVED UNITS.

Units of derived quantities come from a definition of the quantity (usually a formula) and can be expressed as a combination of fundamental units in a given measuring system.

Area: Area is probably the simplest derived quantity. All the familiar formulas for area are of the form:

$$\text{Area} = \text{Constant} \times \text{distance} \times \text{distance} \qquad (1)$$

In some formulas such as the rectangle, the constant is 1 so it doesn't appear in the formula. In the area formula for a circle the distances are identical (radius). The constant has no units in area formulas, but the fundamental units (British) for distance is the foot. According to the formula, the derived unit for area is:

$$\text{feet} \times \text{feet} = \text{feet}^2$$

read feet squared or square feet. The units multiply together just as numbers do in arithmetic, e.g., $3 \times 3 = 3^2$; or as letters do in algebra, e.g., $a \times a = a^2$. You should get used to writing ft^2 for the units of area. It is easier to write than the words square feet or even the abbreviation ft sq. You should also remember that it means ft x ft.

Volume: The volume formulas for common solid objects have the form:

$$\text{Volume} = \text{Constant} \times \text{distance} \times \text{distance} \times \text{distance} \qquad (2)$$

In the British system the derived units are therefore; feet x feet x feet = feet^3. The derivation is similar to that for area.

Velocity: Formulas for velocity have the form:

$$\text{Velocity} = \frac{\text{distance}}{\text{time}} \tag{3}$$

The derived units (British) are feet/second, read feet per second.

Acceleration: Acceleration is the rate of change of velocity:

$$\text{Acceleration} = \frac{\text{velocity}}{\text{time}} \tag{4}$$

Its units, therefore, are feet/second/second = feet/second x 1/second = feet/sec x sec = ft/sec^2. Notice the units can be manipulated just as letters in algebra; to divide by a fraction, you invert the denominator and multiply. The units are read: feet per second squared or feet per second per second.

Mass: The mass of an object is given by the formula:

$$\text{Mass} = \frac{\text{weight}}{\text{acceleration}} \tag{5}$$

Its British units are therefore: $lb/ft/sec^2$ or $lb \cdot sec^2/ft$, read pound second squared per foot. This complex combination of fundamental units is given the name slug for convenience.

Weight: Solving formula (5) for weight, it becomes:

$$\text{Weight} = \text{mass} \times \text{acceleration} \tag{6}$$

Weight is fundamental in the British system but is derived in both absolute systems. The mks unit of weight is kg x m/sec^2 = $kg \cdot m/sec^2$. This combination of units is called the newton. The cgs unit is $g \cdot cm/sec^2$ and is called the dyne.

OTHER DERIVED UNITS.

Other quantities in mechanics have derived units, also. Some examples are: pressure, density, work, power and momertum. See problem sets for their definitions.

OTHER FUNDAMENTAL UNITS.

When studying units of heat, a fourth fundamental unit is required. The unit is that of temperature and is the Celsius degree in the mks system. In physical optics, a fifth fundamental quantity (luminous intensity) has units of candela. In the study of electricity a sixth quantity (electric current) has the unit; ampere. These are all defined independently and, of course, precisely. All are mks units.

ELECTRICAL DERIVED UNITS.

Electric Charge: The defining formula for electric charge is:

$$\text{Electric charge} = \text{current} \times \text{time} \tag{7}$$

Voltage: Potential difference is defined by:

$$\text{Potential difference} = \frac{\text{work}}{\text{charge}} \tag{8}$$

Resistance: Electrical resistance is defined by Ohm's law:

$$\text{Resistance} = \frac{\text{potential difference}}{\text{current}} \qquad (9)$$

The derivation of the units of charge, potential difference and resistance in terms of fundamental units is left as an exercise.

HINTS ON CONVERSION OF UNITS

1. If you wish to express a quantity in smaller sized units, you must have a larger number of them to express the same quantity.
   Examples: 1. 3.5 ft = 42 in
   2. 25 volts = 25 000 mv
   3. 3×10^{-4} amp = 3×10^{-1} ma

   When you work strictly with metric units you must move the decimal to the right or increase the power of 10.

2. If you wish to express a quantity in larger units, you must have a smaller number of them to express the same quantity.
   Examples: 1. 150 min = 2.5 hr
   2. 3.54 w = .00354 kw
   3. 4×10^{5} μa = 4×10^{2} ma

   When you work strictly with metric units you must move the decimal to the left or reduce the power of 10.

3. The following tables list the correct symbols for prefixes and various quantities as established by the 1960 Conference of the International Bureau of Weights and Measures.

Prefixes	Multiple	Symbol
terra	10^{12}	T
giga	10^{9}	G
mega	10^{6}	M
kilo	10^{3}	K
hecto	10^{2}	h
deka	10^{1}	da
deci	10^{-1}	d
centi	10^{-2}	c
milli	10^{-3}	m
micro	10^{-6}	μ
nano	10^{-9}	n
pico	10^{-12}	p
femto	10^{-15}	f
atto	10^{-18}	a

Table 2. Symbols for prefixes

Quantity	Base Unit	Symbol
length	meter	m
volume	liter	l
mass, force	gram, newton	g, N
time	second, hour	s, h
	minute	min
work-energy	joule	J
power	watt	W
current	ampere	A
potential	volt	V
resistance	ohm	Ω
inductance	henry	H
capacitance	farad	F
frequency	hertz	Hz
temperature	Celsius	C^0

Table 3. Symbols for quantities

The following diagram may be helpful in converting units (metric to metric).

If you are starting with a unit and going to a smaller one (moving down ward in table 2), move the decimal to the right or increase the power of 10.

If you are starting with a unit and goint to a larger one (moving upward in table move the decimal to the left or reduce the power of 10.

Figure 1

ACCURACY AND UNCERTAINTY

Every industrial measurement involves error. However, many students are not familiar with the arithmetic of numbers that are not exact. Their mathematical training gave them little or no practice in finding the uncertainty in a product, for example, of two measurements, both of which are uncertain.

Accuracy: The term accuracy of a measurement, although it has various meanings, usually refers to the reliability of a measuring instrument. It is usually expressed by stating the uncertainty in the measurement. The diameter of a crankshaft journal, for example might be 2.125 ± 0.0005 in.

The true or accepted value lies somewhere between 2.1245 in and 2.1255 in. It is impossible to measure the exact value. However, the accuracy can be increased by using more refined measuring instruments.

Uncertainty: The uncertainties or errors in the measurement may be of two classes; erratic or systematic. A systematic error creeps into measurements when measuring devices are not calibratd correctly. All the readings might be systematically too high or too low, for example. Systematic errors contrast with erratic or random errors as the following example indicates.

Hold a slender pointed object such as a ball point pen about an inch above the scale in figure 2 near the 1.5 mark (above the arrow). This arrangement might represent the scale and needle of a voltmeter. Hold your eye about 10 inches above the object and move your head back and forth. The needle appears to give different readings even through you are not moving it. No two people will place their eye in exactly the same place and hence there will be a number of different readings. These different readings are indicative of parallax errors which are of the erratic class.

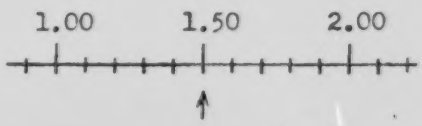


Figure 2

One person might record 1.52, another 1.50. Others might give readings of: 1.46, 1.48, 1.50, 1.48, 1.48, and 1.46. Perhaps when you took your reading, you thought it read 1.50. The mean or average value of the ten readings is: 1/10(1.52 + 1.50 + ...) = 1.49. The voltage, therefore, is 1.49 volts.

The true value, no doubt, lies somehwere between the highest reading (1.52) and the lowest (1.46). We could then represent the reading as 1.49 ± 0.03. However, the uncertainty is probably not as great as 0.03. It will normally not be greater than the average deviation from the mean value. The deviation from the mean is 1/10(0.03 + 0.01 + ...) = 0.017 or approximately 0.02. This would indicate a reading of 1.49 ± 0.02. This value is probably the best value of the voltage we could give from the data taken in the example.

Sometimes the percentage error is given instead of the actual error. This can be found by dividing the actual error (0.02) by the mean value (1.49) and multiplying by 100. The voltage is 1.49 ± 1.34% which is identical to 1.49 ± 0.02.

AN EASIER WAY

When using real measuring instruments, the uncertainties are normally not as large as indicated by the above example. Most measurements are made to an accuracy between 0.1% and 1%. Some of the readings, if they are bad enough, are called blunders and may be dropped from the data.

If the error in the reading, in the example above, was no more than 0.005, we could simply write the mean value as 1.49. When the actual or percentage error is not given, we would assume the true reading lies somewhere between 1.485 and 1.495, in the example. Note that this indicates greater accuracy than 1.49 ± 0.02.

From this point on, we will assume that our measuring instruments are accurate enough to write the numbers in the simplified form.

SIGNIFICANT FIGURES

In the measurement in the example above (1.49), it appears that the first two figures (the one and the four) are quite certain even though not everyone agreed the second figure was a four. Its certainty is derived from the mean value. The third figure (nine) is not so certain. As a matter of fact not one of the ten people recorded it as a nine. The figures that are certain and the first really doubtful one are called significant figures. Thus, the one, the four, and the nine are significant.

CALCULATIONS USING MEASURED VALUES

When you use measured values in calculations, the product or quotient will sometimes end up with many more figures than any of the factors involved.

RULE: Calculated answers of products or quotients should be rounded off so the answer has no more significant figures than the factor that has the least number of significant figures.

Example: Find the area of a circle whose radius is 1.12 in.

$$A = \pi r^2 = 3.1416 \times 1.12 \text{ in} \times 1.12 \text{ in} = 3.94093504 \text{ in}^2$$

The answer indicates an accuracy to the nearest $1/100{,}000{,}000$ in^2. However, the radius was only measured to the nearest 1/100 in. Surely, we cannot know the area as accurately as this. The theory of errors or the simplified rule stated above would indicate that we should round off the answer to three significant figures since the radius was measured to three. So the area is 3.94 in^2. We can use $\pi = 3.14$ for most calculations.

If you use a slide rule, it will automatically round off the answers to three significant figures. However, if you use an electronic calculator, you will have to do the rounding off as an important part of solving problems.

PROBLEMS

Module M 2 SIZING THINGS UP

1. Work out the units of area, volume, velocity, acceleration and weight; express each in fundamental mks units. The defining formulas are given in the information sheet in this booklet.

2. Work out the units of pressure, density, work, power and momentum; express each in fundamental mks units. The defining formulas are:

   a) pressure = $\frac{\text{force}}{\text{area}}$

   b) density = $\frac{\text{weight}}{\text{volume}}$

   c) Work = force x distance

   d) power = $\frac{\text{work}}{\text{time}}$

   e) momentum = mass x velocity

3. Work out the electrical units of potential difference, resistance and electric charge; express each in fundamental mks units. The defining formulas are given in the information sheet in this booklet.

4. Convert the following as indicated:
   a) 235 V to millivolts
   b) 764 mA to amperes
   c) 6.39 kW to milliwatts
   d) 7.5 km to decimeters

5. Convert the following as indicated:
   a) 30 ml to liters
   b) 40 hm to decimeters
   c) .00435 MV to microvolts
   d) 7 380 000 cm to kilometers

6. Convert the following as indicated:
   a) 440 yd to inches
   b) 50 000 oz to tons
   c) 14.7 lb/in^2 to pounds per square foot
   d) 80 mi/h to feet per second

7. Steel cables on the suspension section of the San Francisco Bay Bridge are about 9000 ft long. How many kilometers is this?

8. A building has floor dimensions of 28 by 6 m. Express these dimensions in feet.

9. A 100 ft surveying tape standardized at 60° increases in length by 0.0875 in when used on a certain hot summer day. The tape increased by how many millimeters?

10. An electric motor driving a router runs without a load at 1750 rpm. It makes one revolution every 0.0005714 min. Express this time in decimal form in seconds and milliseconds.

11. A cubic yard of concrete weighs 3900 lb. What is the mass of a cubic yard of concrete in kilograms?

12. A cubic foot of washed sand weighs 95 lb. What is its mass in kilograms?

13. An 18 ft, 2 x 12 in plank made of oak has a mass of 61.5 kg. What is its weight in newtons? In pounds?

14. Packed earth from an excavation weighs 6.5 tons. What is its mass in kilograms?

15. A draftsman spent 17 000 s on a certain job. How many hours is this?

16. In an excavation 480 cubic yards were removed. Express this in cubic meters.

17. A certain house was painted using 8.5 gal of paint. How many liters is this?

18. Underlayment particle board comes in standard 4 x 8 ft sheets. Find the area of one side in square meters.

19. Compare the cubic yard and the cubic meter by calculating the number of cubic feet in each. The cubic yard is what percent of a cubic meter?

20. The small engine driving a portable cement mixer will operate for 0.85 h/gal of gasoline. Convert this rate to seconds of operation per milliliter of gasoline.

21. An exhaust fan on a house circulates air at the rate of 275 ft^3/min. Express this rate in liters per second.

22. In the construction of a dam, water is to be fed to a turbine at the rate of 105 000 l/sec. Express this rate in cubic feet per minute.

23. A contractor paid 7.25 dollars per 50 pounds for 3d common nails. Find the cost in dollars per kilogram.

24. A certain brand of glue cost 1.32 \$/60cc. Find the cost of one pint at the same rate.

25. The cutting edge speed of a large table band saw is 4500 ft/min. Express this speed in miles per hour. In meters per second.

26. Sandstone has a density of 2420 kg/m^3. What is the weight of a cubic foot of sandstone in pounds.

27. Portland cement has a density of 90 lb/ft^3. Express its mass density in grams per cubic centimeter.

28. Freshly fallen wet snow has a density of 15 lb/ft^3. Find the total weight on a 60 ft by 150 ft flat roof if the snow is 3 in deep.

29. The followings readings were made by a group of 11 people: 3.71, 3.68, 3.74, 3.74, 3.75, 3.71, 2.16, 3.70, 3.73, 3.69, 3.72. What is the mean value? Hint: remember that blunders may be dropped. What is the average deviation from the mean? Express the average deviation as a percentage.

30. The following readings were made by a group of 11 people: 5.14, 5.17, 5.19, 5.12, 5.08, 5.21, 5.84, 5.12, 5.19, 5.16, 5.13. Answer the same questions as stated in problem 29.

ANSWER KEYS (PROBLEMS)

Module M 2 SIZING THINGS UP

1. m^2, m^3, m/s, m/s^2, $kg \cdot m/s^2$

2. $kg/s^2 \cdot m$, $kg/s^2 \cdot m^2$, $kg \cdot m^2/s^2$, $kg \cdot m^2/s^3$, $kg \cdot m/s$

3. $kg \cdot m^2/s^3 \cdot A$, $kg \cdot m^2/s^3 \cdot A^2$, $A \cdot s$

4. 2.35×10^5, 0.764, 6.39×10^6, 7.5×10^4

5. 0.030, 4×10^4, 4.35×10^9, 73.8

6. 15 800, 1.56, 2 120, 117

7. 2.74

8. 91.9 x 19.7

9. 2.22

10. 0.03428, 34.28

11. 1770

12. 43

13. 603, 136

14. 5.58×10^5

15. 4.72

16. 367

17. 32.2

18. 2.97

19. 27 ft^3 - 35.3 ft^3, 76.5%

20. 0.81

21. 129

22. 222 000

23. 15.98

24. 10.38

25. 51.1, 22.9

26. 151

27. 144

28. 33 800

29. 3.72, 0.02, 0.54%

30. 5.15, 0.03, 0.58%

EXPERIMENTS

Module M 2 SIZING THINGS UP

PURPOSE: The purpose of these experiments is to study some measuring instruments and methods of precision measurement; to practice estimating distances, mass and volume in metric units; and to compute area, volume and density of various commonly shaped objects.

CAUTIONS:

1. Read all of the instructions before handling any of the equipment.
2. The micrometer and vernier calipers, the Harvard trip balances and the brass weights are all precision instruments. Handle them with care.
3. Keep the plastic foam keeper in place on the Harvard trip balances when they are not in use.
4. Instead of taking the balances to your table to weigh objects, take the objects to the balance for weighing. Balances receive much less wear and tear this way.
5. Never interfere with an experiment someone else is performing or with the equipment they are using. Horseplay is never appropriate in a laboratory situation.
6. Observe all cautions listed in the procedure section of these instructions.

EQUIPMENT: The equipment for each experiment is listed in the procedure section. Check to see if it is all available before you start. Ask your instructor if you have questions about the equipment.

PROCEDURE: Experiment A "Linear Measurement"

Equipment:
1. One 15 cm plastic rule
2. Meter stick
3. Metric tape (10 m)
4. Box A (Objects listed on data sheet)

Estimate the thickness, width, height, etc., for each object listed on the data sheet. Then measure using a 15 cm rule or a meter stick. In the error column, write the difference between the estimated and measured values. Insert a + sign if your estimate is too large and a - sign if it is too small.

Complete one line at a time. Do not make all the estimates before doing any measuring. You should see improvement in your estimates as you proceed one line at a time. Estimate distances to the nearest centimeter in lines 1 through 11. Estimate lines 12 and 15 to the nearest meter. Calculate the areas in line 16 through 18.

Experiment B "Precision Measurement"

Equipment: 1. Sargent-Welch Measurement set #0056

Instructions for reading the micrometer and vernier calipers are given on the information sheet page 19. Practice using both of these instruments as indicated on the data sheet (lines 1 through 10). Calculate the volume of the sphere, small cylinder and the block (lines 11 through 13). Use the micrometer caliper measurements for volume calculations and retain only as many significant digits as is justified.

Experiment C "Volume Measurement"

Equipment:
1. Various bottles listed on the lab sheet (Box C)
2. Various calibrated beakers and Pharmaceutical graduates.

Obtain a 1 to 2 liter beaker and fill it 3/4 full of water. Estimate the volume capacity (level full) of each spoon or bottle listed on the data sheet to the nearest milliliter. Measure each by filling with water. Use a small beaker to pour the water into them.

Pour the water from the bottles into one of the calibrated beakers or pharmaceutical graduates. Measure each as accurately as possible.

CAUTION: Use care not to spill water. Clean up with paper towels. Be careful! You are working with glass.

Complete one line on the data sheet at a time. Do not make all the estimates before measuring. You should see improvement in your estimates as you proceed one line at a time.

In the error column, write the difference between the estimated and measure volumes. Write a + sign if the estimate is too large and a - sign if it is too small.

Experiment D "Mass Measurement"

Equipment:
1. Harvard trip balance (metric)
2. Box D. Various objects listed on lab sheet D.

Use the dynamic method of balancing (see information sheet page 19) to find the mass of each object listed on the lab sheet. Measure each object to the nearest 0.1 grams.

CAUTION: The maximum capacity is 1500 grams or 4 pounds. Do not overload

Calculate your mass in kilograms (line 9) and then measure it on the metri bathroom scale.

Experiment E "Density"

Equipment:
1. Vernier caliper
2. Harvard trip balance
3. One object in box E

Use a vernier caliper to measure the dimensions of one of the blocks in box E. (How to use the vernier caliper is described in the information sheet, page 19.) Measure the height along each of the four sides and calculate the average. Record all data. Record four measurements of the length and width and the average of each. Make your measurements to the nearest 0.01 mm.

Using the average values of length, width and height, calculate the volume of the block (line 4).

Measure the mass of the block to the nearest 0.1 gram using the dynamic method (see information sheet, page 19). (Line 4.)

Calculate the density using measured values of mass and volume. (Line 6.)

Substance	Density kg/m^3	lb/ft^3
Aluminum	2,650	164
Brass	8,600	535
Iron	7,800	480

Table 4.

Compare calculations of density with that in Table 4 by calculating the percentage error.

$$\% \text{ error} = \frac{\text{difference}}{\text{standard value}} \times 100$$

INFORMATION: The following information about the micrometer caliper, the vernier caliper and the balance scale are included here for your convenience.

Use of the Harvard Trip Balance.

The Harvard trip balance uses a method of weighing by direct comparison with standard weights. The single beam balance is sensitive to 0.1 gram and the beam is graduated for 10 grams. The double beam balance (Figure 6) permits weighing up to 210 grams without added weights. The lower scale reads to 10 grams in 0.1 gram divisions. The upper scale reads to 200 grams in 10 gram divisions. The British balance back beam reads to 8 oz in 1 oz divisions while the front beam reads to 1 oz in either 0.01 oz or 1/64 oz divisions.

Figure 6.

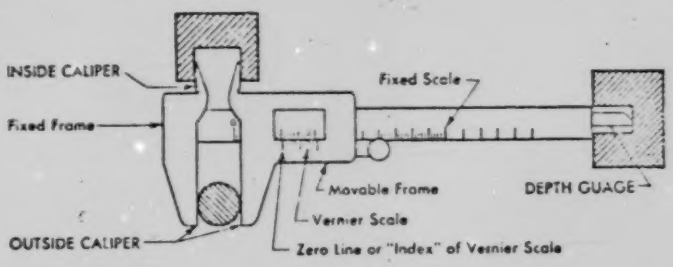
CAUTION: Maximum recommended capacity is 1500 grams or 4 lb.

Do not attempt to balance the scale with the pointer stopped on the center mark. Use a dynamic method of weighing; with the pans in motion, the pointer should swing the same amount on each side of the center mark. This method eliminates the slight amount of internal friction of the balance. Place the object to be weighed on the left pan; the standard weights on the right. Adjust slider on the balance beam to correct position for dynamic balance.

Use of the Vernier Caliper.

"By permission from Sargent-Welch Scientific Company, Instructions for the use of Measurement Set Cat. No. 0056"

Measurements are made by sliding the movable frame along the fixed scale so that either the inside or outside caliper or the depth gauge covers the distance to be measured. See Figure 1. The caliper or depth indicator should fit snugly against the object to



be measured. Use the knurled thumb nut for this adjustment. Once the caliper or depth indicator is firm against the object to be measured, read the graduation on the fixed scale nearest the zero mark on the vernier scale. If the zero mark does not coincide with a fixed-scale graduation, add the appropriate distance as read from the vernier scale.

Some examples in reading a vernier scale follow:

In Figure 2a, the distance is read as follows;

1. First read the fixed scale. Note that the zero line of the moveable scale does not coincide with a division on the fixed scale. Read the division on the fixed scale just to the left of the zero line. This reading is 3.70.
2. The distance from the division just to the left of the zero line to the zero line is determined as follows. Starting from the zero line and moving to the right, count the lines on the vernier scale until a line is reached which most nearly coincides with a division on the fixed scale. In the example, this number is four.
3. Add 3.70 cm and 0.04 cm to get 3.74 cm.

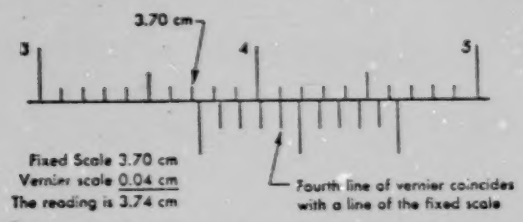


Figure 2a

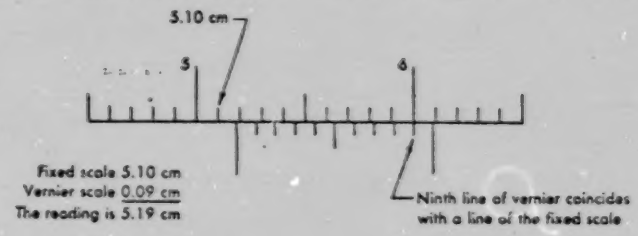

5.10 cm
5
6
Fixed scale 5.10 cm
Vernier scale 0.09 cm
The reading is 5.19 cm
Ninth line of vernier coincides with a line of the fixed scale

Figure 2b

The same procedure applies to reading the vernier on the British scale, but with each division on the vernier representing 1/100 of an inch.

Use of the Micrometer Caliper.

"By permission from Sargent-Welch Scientific Company,
Instructions for the Use of Measurement Set Cat. No. 0056

The micrometer caliper in the measurement set has a pitch of 0.5 mm. This means that the screw advances 0.5 mm when turned through one revolution. Fractional revolutions of the screw are indicated by the graduations on the circumference of the thimble. See Figure 3. The scale around the circumference of the thimble is divided into 50 parts. Each division represents 1/50 of a revolution. When the thimble is turned through one division, the screw advances 1/50 of the pitch, i.e., 1/50 of 0.5 mm, or 0.01 mm.

Example: In Figure 4a, the thimble has been rotated through a fraction more than sixteen revolutions from zero. This corresponds to a distance of 8.00 mm, i.e.,
16 rev x 0.500 mm/rev = 8.00 mm.
The fractional revolution is 0.110 mm plus the length represented by the distance from the eleventh

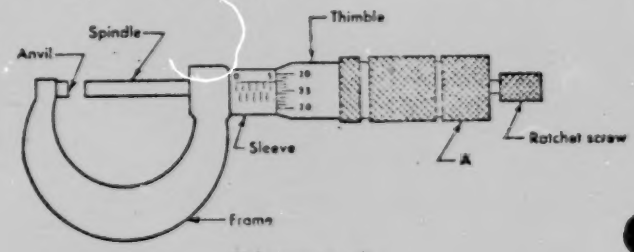


Figure 3.

sleeve graduation to the spindle reference line. The reference line is approximately one-half of the way between the 11th and 12th sleeve graduation. Since these graduations represent 0.01 mm of measured distance, this fraction may be estimated as 0.005 mm.

Caution: Use the ratchet screw to avoid tightening the jaws so much that the frame will be strained. Always store the micrometer caliper with the jaws open. If the jaws are closed and the temperature increases, the frame may warp.

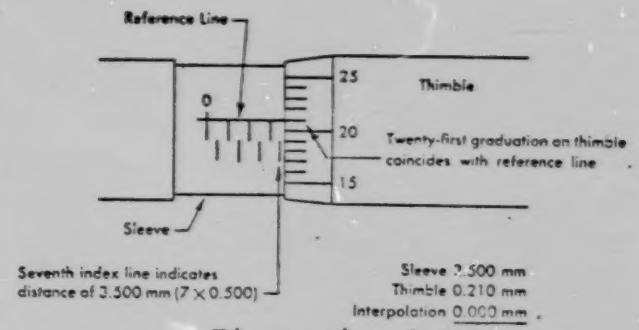


Figure 4a.

Additional examples are given in figures 4b and 4c.

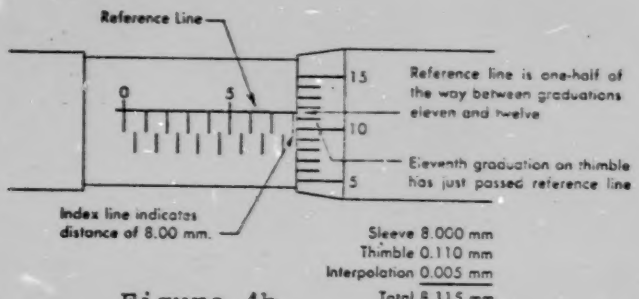


Figure 4b.

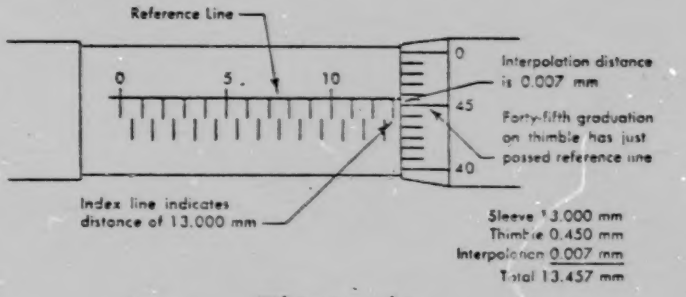


Figure 4c.

Use of the Rule.

"By permission from Sargent-Welch Scientific Company, Instructions for the use of Measurement Set Cat. No. 0056

There are a number of acceptable methods for use of the rule in measuring a given dimension of an object. One suggested method is to lay the rule across a flat portion of the object to be measured as shown in Figure 5.

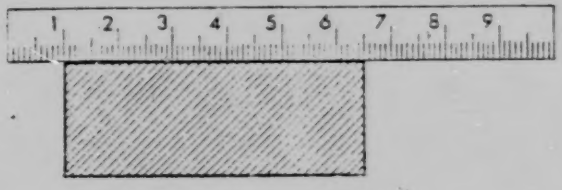


Figure 5.

Some graduation such as the 1-cm mark is lined up exactly with the left edge, and the reading of the rule at the right edge is made and recorded. The dimension of the object is obtained by subtracting the reading of the rule at the left edge (1.00 cm) from the reading at the right edge.

Applied Physics Module

SOUTHEAST COMMUNITY COLLEGE—Milford Campus Milford, Nebr. 68405

Module M 3

Title: The Nature of Vectors

Module Contents:
1. Vectors
2. Composition of vectors
3. Resolution of vectors
4. Displacement
5. Equilibrium of concurrent forces

Program: This units has been prepared especially for students in:
1. Surveying and drafting
2. Architectural drafting technology
3. Building construction technology

Purpose: Equilibrium of bridges, towers, buildings, and other structures requires balance of forces and torques. Forces, torques, displacement, velocities, and other vectors have directions associated with them. Balancing forces and torques require a thorough knowledge of the addition of vectors. This module is a pre-requisite for others that follow. Practical applications involving guy-wires on towers, forces on bridges, and other structures are included.

Producer: Gene Waring

Date Produced: August 1976

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STUDENT INSTRUCTIONS

Module M 3 THE NATURE OF VECTORS

OBJECTIVES

When you have satisfactorily complete this module, you will be able to:

1. Define the following words and terms: vector, scalar, magnitude, line of application, point of application, concurrent forces, equilibrium, resultant, equilibrant, vector component, vector composition, and vector resolution.
2. Represent a vector quantity (both magnitude and direction) by an arrow.
3. Construct space (free body) diagrams.
4. Construct freehand vector diagrams and estimate the vector sum or difference (magnitude and direction) using the parallelogram or polygon methods.
5. Resolve a vector into its rectangular components given the magnitude and direction (Polar form).
6. Find the magnitude and direction (Polar form) of a vector given its rectangular components.
7. Find the vector sum or difference of vectors by the component method.
8. Apply the methods of vector addition to various practical problems involving displacement and concurrent forces.
9. Solve practical problems involving the equilibrium of objects under the influence of a set of concurrent forces.

In order to satisfactorily complete this module, you must pass a test consisting of true-false, multiple choice, and problem type questions based on the objectives listed above with a grade of at least 80%.

SELF-EVALUATION TEST

Perhaps you have had previous experience with the study of vectors. You may feel that your experience will enable you to perform most of the tasks listed in the objectives section above. A self-evaluation test (or sample test) is included in this booklet (pink paper, page 5) along with an answer key. You can evaluate your previous knowledge of the subject by taking this test (under normal test conditions) before you perform any of the learning activities listed below.

The result of this test is an indication of your knowledge. If you can answer all questions correctly, you may not need additional

study. However, you should proceed with the learning activities if you can't answer all questions correctly. The answer key page (pink, page 6) directs you to various learning activities.

LEARNING ACTIVITIES

The following list of activities is designed to help you achieve the objectives of this module. You are not required to complete all of the activities. They are intended to supplement your previous knowledge of the subject. If you wish, your instructor will recommend the learning activities you should complete.

Before you take the instructor-graded test (post-test), read the "test" section at the end of these instruction pages (white paper, page 4).

I. Reading: The chapters, sections and page numbers are given for several textbooks. You may select your own textbook. As you read, keep the list of objectives handy. Write down on separate paper a list of the definitions, laws, principles, formulas, etc., that the objectives refer to. This list will be very useful as an aid to memorizing them.

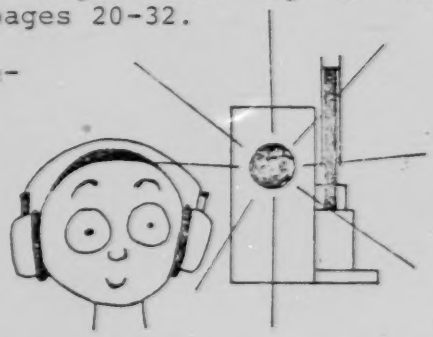
A. Introductory Applied Physics, Harris, N.C., Hemmerling, E.M., McGraw-Hill, 3rd ed., 1972. Read part of chapter 5, pages 113-121, and 125-128. (Omit sections 5-9 and 5-11)

B. Elements of Physics, Smith A.W., Cooper, J.N., McGraw-Hill, 8th ed., 1972. Read all of chapter 2, pages 16-23.

C. Physics for Career Education, Ewen, D., Nelson, R., Schurter, N., McFadden, L., Prentice-Hall Inc., 1st ed., 1974. Read all of chapters 7 and 8, pages 70-100.

D. Physics for Technology, Betts, J., Reston Publishing Co. Inc., 1st ed., 1976. Read part of chapter 2, pages 12-20. (Omit sections 2-4)

E. Modern Technical Physics, Beiser, A., Cummings Publishing Co. Inc., 1st ed., 1966. Read all of chapter 2, pages 20-32.



II. Listening/Viewing: The following single-concept film loops (8 mm) are available in the Learning Resource Center (LRC). There is a brief training session given by the LRC staff to familiarize you with the film-loop projector (Technicolor) and must precede the viewing of the films. Ask the LRC personnel about this training.

A. The Velocity Vector, (BFA Ealing 80-251)

B. Vector Addition-Velocity of a boat, (BFA Ealing 80-3478)

III. Solving Problems: Solve the problems in the problem set in this booklet. They are printed on ivory paper (page 10). Answers are given for each problem. Solve as many of them as you feel are necessary to gain competence in manipulating vectors. Most of the problems from number six on are applied to your technology.

IV. Solving Problems (Optional): Solve some of the problems at the end of the reading set in your textbook. These are for additional practice if you feel it is needed and are mostly general interest problems.

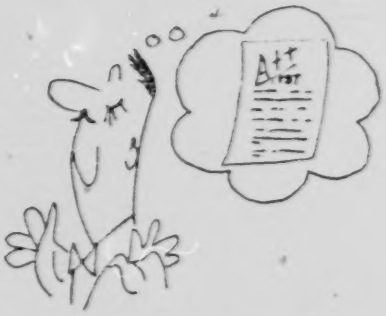
V. Performing Laboratory Experiments: There is one experiment in this module. It will give you practice in learning about vector addition of concurrent forces.

Read the laboratory instruction in this booklet on yellow paper and pay particular attention to the cautions given. Obtain a laboratory data sheet (M-3) and the equipment from the instructor. Keep this booklet open to the instruction pages and proceed step by step with the experiment.

TEST

You may proceed with the test at any stage of your study of this module; obtain a copy of the test, answer all questions and return it to your instructor.

A grade of 80% is required for satisfactory completion of the module. A grade lower than 80% will require that you repeat the test. You must show evidence of further study before you repeat it, however. (Hand in your papers on problem solving, lab reports, etc.)



Every test you take on this module will be averaged to determine your module grade. Don't take the test until you have adequately prepared yourself to meet the requirements listed in the objectives section. Instead, go to the learning activities.

SELF-EVALUATION TEST

Module M 3 THE NATURE OF VECTORS

Read each question carefully and decide which one of the answers is best. Notice what letter your choice is. Then, on separate paper, write the problem number followed by the letter you chose. Take the test under normal test conditions; without help from other people and without references. The answer key is on the following page. DO NOT WRITE ON THIS TEST!

T - F 1. A vector is a quantity that is represented by a number, unit, and a direction.

T - F 2. A force of 25 lb makes an angle of 35° with the x-axis, its component in the y-direction is 14.3 lb.

T - F 3. Vector diagrams need not be drawn to accurate scale for the resultant to be shown correctly.

T - F 4. Displacements of 5, 9, 22, and 38 miles would allow an automobile to return to its starting point if the directions happen to be in a correct combination.

T - F 5. The process of separating vectors into their rectangular components is called vector resolution.

6. A force of 90 N makes an angle of 25° with the x-axis. Its horizontal component in newtons is:

a) 81.6 c) 38.0
b) 99.3 d) 213

7. Displacements of 15 km and 5 km, if the directions were correct, could be added to give a resultant magnitude in kilometers of:

a) 0 c) 17
b) 22 d) 4

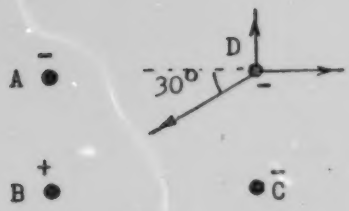
8. A force of 8 N acts perpendicular to a force of 11 N. The resultant has a magnitude in newtons of:

a) 19 c) 3
b) 13.6 d) 185

9. An automobile travels 6 miles north and then 6 miles in a direction 30° east of north. The magnitude of the resulting displacement in miles is:

a) 12.0 c) 9.00
b) 11.6 d) 36.0

10.



Four electric charges are located at the vertices of a rectangle as shown in the diagram. Each charge exerts a force on each of the others. The forces on charge D are F_A = 7 dynes, F_B = 10 dynes, and F_C = 15 dynes, with directions shown on the diagram. Find the resultant (magnitude and direction) of the forces on charge D.

11. Construct a careful freehand vector parallelogram on graph paper. Plot the following pair of forces: 28.2 N at 256°, and 37.1 N at 329°. Both angles are measured from the positive x-axis. Draw in the resultant and estimate its magnitude and direction.

ANSWER KEY TO THE SELF EVALUATION TEST

Module M 3 THE NATURE OF VECTORS

Question-Answer	If you missed this question, you are directed to these learning activities:
1. T	I. Reading or II. Listening/Viewing
2. T	III. Solving Problems
3. F	I. Reading or V. Performing Laboratory Experiments
4. F	III. Solving Problems
5. T	I. Reading or II. Listening/Viewing
6. a	III. Solving Problems
7. c	III. Solving Problems
8. b	III. Solving Problems
9. b	III. Solving Problems

10. 10.1 dynes at 99.4° from the x-axis

V. Performing Laboratory Experiments

11.

52.8/-61.8

III. Solving Problems or
V. Performing Laboratory Experiments

(Your estimate should be reasonable close)

PROBLEMS

Module M 3

1. What is the relationship between the resultant and the equilibrant of two or more forces?

2. Can the resultant of two unequal displacements be zero? Explain:

3. Can the resultant of three unequal displacements be zero? Explain:

4. Can either of two rectangular components of a displacement be larger than the displacement itself? Explain:

5. Does the odometer on a car measure a vector or scalar quantity? What quantity does it measure?

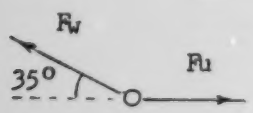
6. Two concurrent forces of 100 N and 75 N act on a body. What are the maximum and minimum possible magnitudes of the resultant force?

7. Find the east-west and north-south components of the force caused by the wind on a tower if the wind is blowing in a direction toward 30° south of east. The magnitude is 2856 lb.

8. Find the horizontal and vertical components of the tension of 3450 lb in a utility pole guy-wire that makes an angle of 40° with the horizontal.

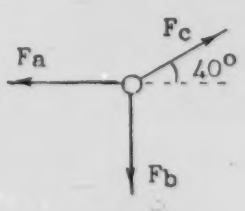
9. Which of the following can be represented by a vector: (a) side force on a structure caused by the wind, (b) the wind, (c) the motion of an electron, (d) the mass of an earth fill dam, (e) the direction: 30° east of north, (f) the heat energy produced by a gas furnace, (g) the force of gravity.

10. Find the east-west and north-south components of a displacement to a construction site if it is 23.7 miles at 38.5° west of south from the surveying office.

11. 

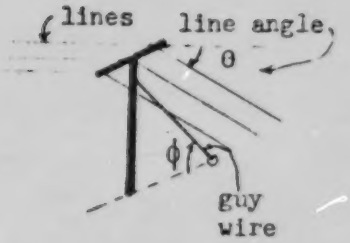
A tower has a pull on it (F_u) of 5280 lb due to the weight of utility lines and an additional force (F_w) of 2560 lb due to the wind in a direction shown in the diagram. What is the net force on the tower?

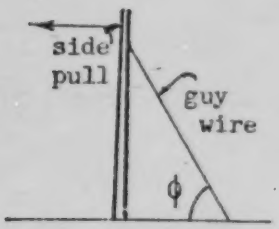
12. A part of a bridge structure has forces on it with directions shown in the diagram. If F_A is 3280 lb, F_b = 4560 lb, and F_c = 7120 lb, find the net force on the structure.



PROBLEMS CONTINUED:

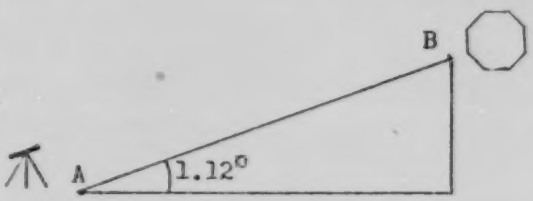
13. A transmission line makes a line angle of 30° (see sketch). If each of three #2 copper lines exert a pull of 1522 lb on the pole in both directions, find the side pull on the pole.

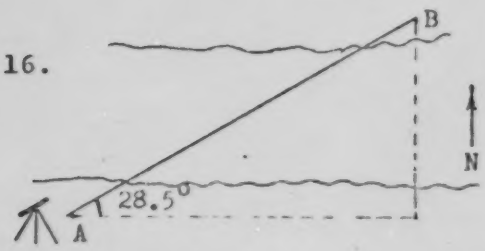


14. 

A guy-wire (see sketch) is used to balance the side pull of the pole in problem 13. The horizontal component of the guy-wire tension must equal the side pull due to the lines. Find the tension in the guy-wire if it makes an angle (ϕ) of 45° with the ground.

15. An exit ramp on I-80 is a straight incline. A transit indicates the length of the ramp is 874 ft and rises at an angle of 1.12°. Find the horizontal distance from point A (transit) and a point directly below B (stop sign). What is the vertical rise of the incline?



16. 

A surveying team measures the distance across a stream (point A to point B). What is the east-west component of this measurement if the distance from A to B is 1128 m? What is the width of the stream?

17. The range of a CB radio is 24 km. If a surveying party is located 15 km north and 14 km west of the carrier truck, will the surveying party be able to tell the driver how to reach them?

PROBLEM ANSWER KEYS

Module M 3 THE NATURE OF VECTORS

1. Equal magnitude, opposite direction
2. No
3. Yes, if directions are correct and if one is not greater than the sum of the other two.
4. No
5. Scalar, distance traveled
6. 175 N, 25 N
7. 2470 east, 1430 south
8. 2640 lb, 2220 lb
9. a, b, c, g
10. 14.8 west, 18.6 south
11. 2080 lb at 135° from positive x-axis
12. 2170 lb at 0.53° from positive x-axis
13. 788 lb at 75° from either line
14. 1100 lb
15. 874 ft, 17.1 ft
16. 991 m, 538 m
17. Yes, distance apart is 20.5 km

EXPERIMENTS

Module M 3 THE NATURE OF VECTORS

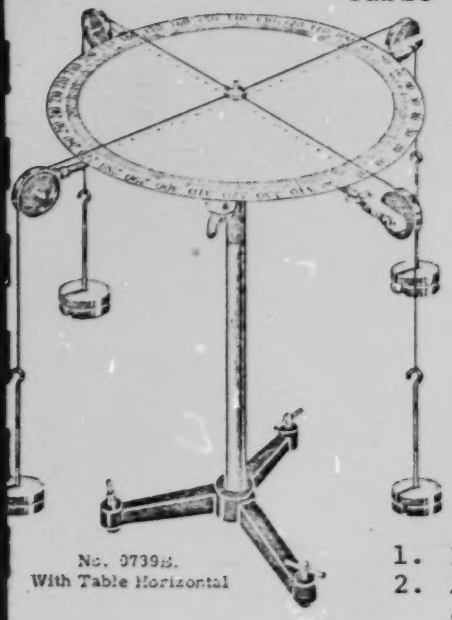
PURPOSE: The purpose of this experiment is to study the vector sum of several concurrent forces, to evaluate the equilibrant of the forces, and to study the resulting equilibrium.

CAUTIONS:

1. Read all of the instructions before handling any of the equipment.
2. Never interfere with an experiment someone else is performing or with the equipment they are using.
3. Observe all cautions listed in the procedure section of these instructions.

INFORMATION: A set of forces, acting on the same object, whose line of actions all intersect at the same point is said to be a concurrent set of forces. The vector sum of a set of concurrent forces is called the resultant and the same results will be obtained. An additional force called the equilibrant of the set of forces is equal in magnitude but opposite in direction to the resultant. Both the resultant and the equilibrant are concurrent with the original set of forces. When the equilibrant is applied to the object along with the original set of forces, the object comes to an equilibrium situation. Graphical and analytical methods of finding the resulant and equilibrant are described in your textbook or in the information sheet, page , of this booklet.

Equipment: Sargent Welsh, catalog number 0739B, Kennon Force Table consisting of the following parts (see Fig. 1):



No. 0739B.
With Table Horizontal

1. Table top with a 360° circle etched on the surface.
2. Pulleys and pulley support rods.
3. A support rod and tripod base.
4. Accessories consisting of weight hangers, metal ring, string, slotted weights, and small level.

Check to see that all the equipment is available before you start. Ask your instructor if you have any questions about the equipment.

PROCEDURE:

1. Place the aluminum disc on a table with its face down.
2. Adjust the pulleys so that they are pointed radially outward from the center of the table top. Observe that the position of each pulley can be adjusted 45° on each

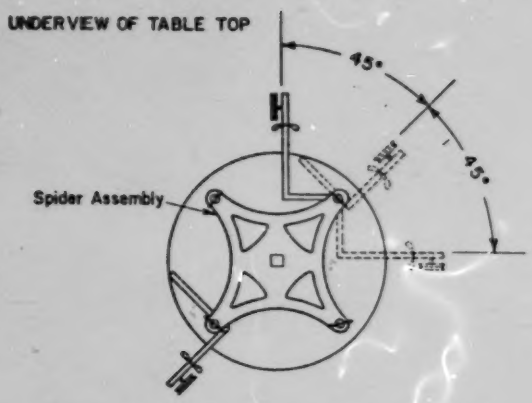


Figure 2.

side of the spider arm to which it is attached. Note that when a pulley is pointing radially outward near the spider arm, it is clamped near the bend in the pulley support rod. When a pulley is pointing radially outward between two spider arms, it is clamped near the end of the pulley support rod (see Figure 2).

3. Make the adjustments so that three pulleys are at about 0°, 50° to 75° and -100 to -130°. Leave the fourth pulley for later adjustment. Mount the support rod on the tripod base.
4. Mount the table on the support rod in the horizontal position. For the horizontal position, the axis of each pulley wheel must be parallel to the plane of the table and perpendicular to the axis of the table.
5. Level the assembly using the leveling screws in the base.
6. Attach strings to the metal ring and weight hangers and place the strings in the grooves of the pulleys as shown in Figure 1 with the metal ring on the center peg.
7. Place slotted weights of unequal amounts on the three hangers. Use 100 g to 400 g including the 50 g weight of the hanger.
8. Record the three forces (magnitude and direction) in the table on the data sheet.
9. Make a vector polygon of the three forces. Estimate the resultant.
10. Use the analytical method and determine the resultant and equilibrant (magnitude and direction).
11. Adjust the fourth pulley so the fourth string will pull in the direction of the equilibrant.
12. Add weight to the fourth hanger equal to the magnitude of the equilibrant.
13. Test for equilibrium as follows: Equilibrium will be attained when the ring is at rest at the center of the table. Raise the ring a few centimeters above the force table and release it. If the ring returns to the center, equilibrium has been established and the friction in the pulleys is a minimum. If the ring does not return to the center, the forces are not in equilibrium and you should repeat your calculations.
14. Write down your conclusions and observations in the space provided on the data sheet.

"Diagrams and part of the written material in the equipment and procedure section used by permission from Sargent-Welch Scientific Company, Instructions for the use of Kennon Force table."

Applied Physics Module

SOUTHEAST COMMUNITY COLLEGE—Milford Campus Milford, Nebr. 68405

Module: M 4

Title: Static Equilibrium

Module Contents:
1. Moment of force (torque)
2. Center of gravity
3. Types of equilibrium
4. Equilibrium (parallel forces)
5. Equilibrium (non-parallel, non-concurrent forces)

Program: This unit has been prepared especially for students in:
1. Surveying and drafting
2. Architectural drafting technology
3. Building construction technology

Purpose: The purpose of this module is to extend the study of vector addition and resolution. The laws of static equilibrium in two dimensions are introduced. Applications involving trusses, scaffolding, gates, ladder, etc., are included.

Producer: Gene Waring

Date Produced: August 1976

This project was performed pursuant to a grant from the State Board of Vocational Education through the Nebraska Research Coordinating Unit using federal funds made available under Public Law 90-576 part C, Research.

STUDENT INSTRUCTIONS

Module M 4 STATIC EQUILIBRIUM

OBJECTIVES

When you have satisfactorily completed this module, you will be able to:

1. Define the following words or terms: moment, turning moment, torque, moment of force; center of rotation, moment center or fulcrum; center of gravity; moment arm or lever arm; and equilibrium.
2. Construct free body diagrams and vector diagrams for specific rigid body problems.
3. Recognize the greek capital letter sigma and state the mathematical meaning it represents.
4. State the two conditions of equilibrium.
5. Use the laws of equilibrium to solve practical problems (parallel forces) including the location of the center of gravity.
6. Use the laws of equilibrium to solve structural problems including the location of the center of gravity (non-parallel, non-concurrent forces).

In order to satisfactorily complete this module, you must pass a test consisting of true-false, multiple choice, and problem type questions based on the objectives listed above with a grade of at least 80%.

SELF-EVALUATION TEST

Perhaps you have had previous experience with the study of equilibrium. You may feel that your experience will enable you to perform most of the tasks listed in the objectives section above. A self-evaluation test (or sample test) is included in this booklet (pink paper, page 5) along with an answer key. You can evaluate your previous knowledge of the subject by taking this test (under normal test conditions) before you perform any of the learning activities listed below.

The result of this test is an indication of your knowledge. If you can answer all questions correctly, you may not need additional study. However, you should proceed with the learning activities if you can't answer all questions correctly. The answer key page (pink paper, page 5) directs you to various learning activities.

Before you take the instructor-graded test (post-test), read the "test" section at the end of these instruction pages (white paper, page 4).

LEARNING ACTIVITIES

The following list of activities is designed to help you achieve the objectives of this module. You are not required to complete all of the activities. They are intended to supplement your previous knowledge of the subject. If you wish, your instructor will recommend the learning activities you should complete.

I. Reading: The chapters, sections and page numbers are given for several textbooks. You may select your own textbook and the information sheet that is included in this booklet. As you read, keep the list of objectives handy. Write down on separate paper a list of the definitions, laws, principles, formulas, etc., that the objectives refer to. This list will be very useful as an aid to memorizing them.

A. Information Sheet. Read the information sheets included in this booklet. They are printed on green paper (page 8). The information sheets cover subject matter that is presented only briefly or not at all in the textbooks. (For those using texts B and D only)

B. Introductory Applied Physics, Harris, N.C., Hemmerling, E.M., McGraw-Hill, 3rd ed., 1972. Read part of chapter 5, pages 121-125, sections 5.8 and 5.9. Also read information sheets.

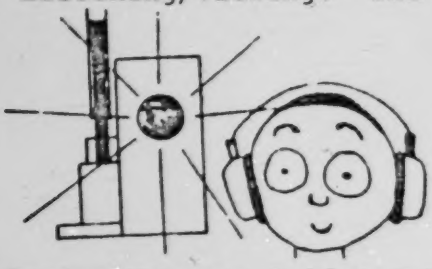
C. Elements of Physics, Smith, A.W., Cooper, J.N., McGraw-Hill, 8th ed., 1972. Read all of chapter 4, pages 37-44.

D. Physics for Career Education, Ewen, D., Nelson, R., Schurter, N., McFadden, L., Prentice-Hall Inc., 1st ed., 1974. Read all of chapter 13, pages 174-180 and information sheets.

E. Physics for Technology, Betts, J., Reston Publishing Co. Inc., 1st ed., 1976. Read part of chapter 10, pages 119-126 and 130-138. (Omit section 10.6)

F. Modern Technical Physics, Beiser, A., Cummings Publishing Co. Inc., 1st ed., 1966. Read part of chapter 7, pages 94-100. (Omit section 7-1)

II. Listening/Viewing: The following single concept film loops (8 mm) are available in the Learning Resource Center (LRC). There is a brief training session given by the LRC staff to familiarize you with the film loop projector (Technicolor or Viewlex 702) and must precede the viewing of the films. Ask the LRC personnel about this training.



A. Tacoma Narrows Bridge Collapse, (BFA Ealing 80-2181)
B. The Center of mass, (BFA Ealing - 3148)
C. Dynamics Response of a Suspension Bridge, (AAPT Physics film #17)

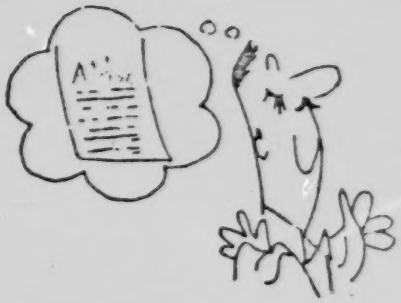
III. Solving Problems: Solve the problems in the problem set in this booklet. They are printed on ivory paper (page 10). Answers are given for each problem. Solve as many of them as you feel are necessary to gain competence in solving equilibrium of rigid body problems. The problems from number five on are applied to your technology.

IV. Solving Problems (Optional): Solve some of the problems at the end of the reading set in your textbook. These are for additional practice if you feel it is needed and are mostly general interest problems.

V. Performing Laboratory Experiments: There is one experiment in this module. It will give you practice in learning about torque, center of gravity, and equilibrium.

Read the laboratory instructions in this booklet (on yellow paper, and pay particular attention to the cautions given) Obtain a laboratory data sheet (M-4) and the equipment from the instructor. Keep this booklet open to the instruction pages and proceed step by step with the experiment.

TEST



You may proceed with the test at any stage of your study of this module; obtain a copy of the test, answer all questions, and return it to your instructor.

A grade of 80% is required for satisfactory completion of the module. A grade lower than 80% will require that you repeat the test. You must show evidence of further study before you repeat it, however. (Hand in your papers on problem solving, lab reports, etc.)

Every test you take on this module will be averaged to determine your module grade. Don't take the test until you have adequately prepared yourself to meet the requirements listed in the objectives section. Instead, go to the learning activities.

SELF-EVALUATION TEST

Module M 4 STATIC EQUILIBRIUM

Read each question carefully and decide which one of the answers is best. Notice what letter your choice is. Then, on separate paper, write the problem number followed by the letter you chose. Take the test under normal test conditions; without help from other people and without references. The answer key is on the following page.

T - F 1. The magnitude of a moment of force depends on how far the force is from the center of gravity.

T - F 2. A group of parallel forces cannot be concurrent.

T - F 3. The vector sum of the forces acting on an object in equilibrium must be equal to zero.

T - F 4. It is not possible for: "an object to be in linear equilibrium but not rotational equilibrium at the same time."

T - F 5. A body that remains at rest is said to be in a state of static equilibrium.

6. The unit of torque in the British measuring system is:

a) ft/lb c) $lb \cdot ft^2$
b) lb·ft d) lb/ft

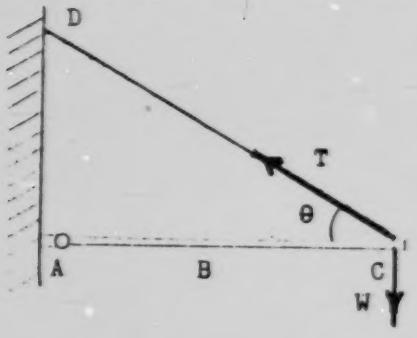
7. Which of the following group of parallel forces cannot be in equilibrium?

a) 7, 14, and 21 N c) 10, 40, and 20 dynes
b) 3, 7, and 4 lb d) 15, 30, 15 oz

8. A uniform steel rod is 3 m long and weighs 125 N. It has a load of 175 N attached at one end. The balance point from the loaded end in centimeters is:

a) 62.5 c) 210
b) zero d) 100

9. A 36 ft, 400 lb utility pole has its center of gravity 14.5 ft from the heavy end and rests on supports at each end. Two 265 lb loads are located at 10 ft and 25 ft, respectively from the heavy end. What are the reactions at each end?

10. 

A 70 N horizontal bar (AB) is 3 m long and has its center of gravity at B, 75 cm from pin A. A weight of 250 N is located at C on the end of the bar. The angle is 65°. Find the tension in the cable (CD).

ANSWER KEY TO THE SELF-EVALUATION TEST

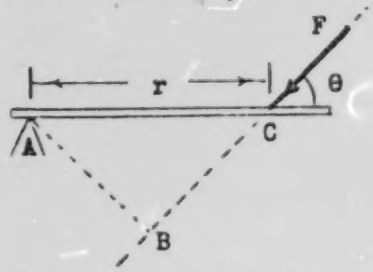
Module M 4 STATIC EQUILIBRIUM

Question-Answer	If you missed this question, you are directed to these learning activities
1. F	I. Reading or II. Listening/Viewing
2. T	I. Reading
3. T	I. Reading or III. Solving Problems
4. F	I. Reading or III. Solving Problems
5. T	I. Reading
6. b	I. Reading or III. Solving Problems
7. c	III. Solving Problems or V. Performing Laboratory Experiments
8. a	III. Solving Problems or V. Performing Laboratory Experiments
9. 511 lb, 419 lb	III. Solving Problems or V. Performing Laboratory Experiments
10. 295 N	III. Solving Problems

INFORMATION SHEET

Module M 4 STATIC EQUILIBRIUM

The following information is included for those students using textbooks A and C (See STUDENT INSTRUCTIONS, page). These text do not cover objective #6 (STUDENT INSTRUCTIONS, page) dealing with non-parallel, non-concurrent force problems.



MOMENT OF FORCE

The moment of force (torque) on an object is the product of the force and its moment arm (lever arm). When a force is applied to an object as in Figure 1, it acts along a line CB called the line of action of the force. The moment arm is the shortest distance between the axis of rotation or fulcrum to the line of action. Thus: the moment arm for force F in Figure 1 is the distance AB. It may be calculated by the formula: AB = r sin θ. The moment of force or torque (T), therefore, is:

$$T = Fr \sin \theta$$

You can readily see that the torque does depend on the angle at which the force is applied. The torque on a wrench, for example, is greatest when the force is applied perpendicular to the handle ($\theta = 90°$).

EQUILIBRIUM (non-concurrent, non-parallel forces)

The laws of equilibrium for co-planar forces are:

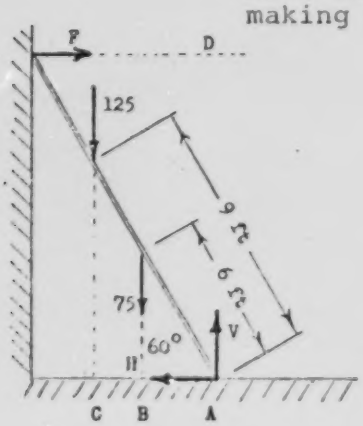
1. $\Sigma F_x = \Sigma F\text{-}x$
2. $\Sigma F_y = \Sigma F\text{-}y$
3. $\Sigma T_{cw} = \Sigma T_{ccw}$

The following examples illustrate the application of these laws to non-parallel forces.

EXAMPLE 1: A 16 ft, 75 lb ladder has its center of gravity 6 ft from the bottom end. It leans against a building making a 60° angle with the ground. A woman weighing 125 lb stands on a rung 9 ft from the bottom end. Find the horizontal (H) and vertical (V) components of the force exerted on the ladder by the wall. Assume the wall is frictionless so that F is horizontal. Write the three laws as they apply to this problem:

1. F = H
2. V = 125 + 75

Choose the fulcrum to be at the lower end of the ladder so forces V and H



exert no torques and are thus eliminated from equation three:

3. (75 x 6 cos 60°) + (125 x 9 cos 60°) = F x 16 sin 60°

Note that 6 cos 60 is the distance AB, 9 cos 60 is the distance AC and 16 sin 60° is the distance AD.

Now observe the three equations. F is the only unknown in equation 3, V is the only unknown in equation 2, and can be solved immediately: F = 56.8 lb, V = 200. From equation 1 we see that H = F = 56.8 lb.

EXAMPLE 2: A 7 x 3 ft, 60 lb door hangs from two hinges. One hinge is 1 ft from the top; the other is 1 ft from the bottom. The center of gravity is at the geometric center of the door. Find the horizontal and vertical components of the reactions on the hinges if the lower hinge supports 2/3 of the weight of the door.

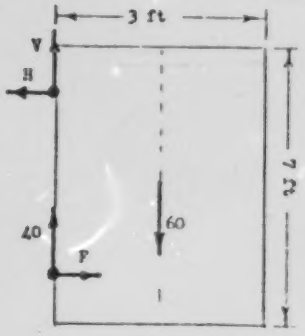


Figure 3

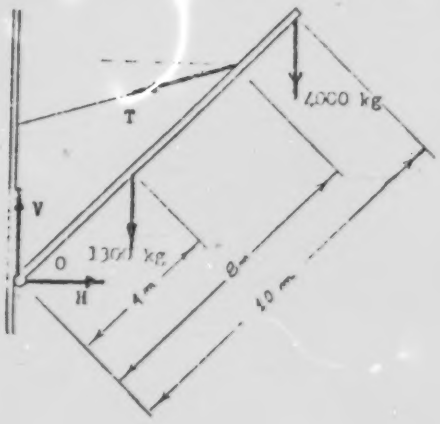
Note that 2/3 of the weight is 40 lb so the vertical component of the lower reaction is 40 lb. Write the three equations applied to this problem:

1. H = F
2. V + 40 = 60

Choose the fulcrum at the upper hinge to eliminate V and H from the third equation. Note that this also eliminates the 40 lb force since its line of action passes through the fulcrum and therefore has a zero lever arm. 3. F x 5 = 60 x 1.5 Note that the 5 ft is the distance from the fulcrum (upper hinge) to the line of action of F, and the 1.5 ft is the distance from the fulcrum to the line of action of the door's weight. Now, observe the three equations: F can be found in equation 3, V in equation 2, and H in equation 1 after F is found. F = 18 lb, V = 20 lb, and H = 18 lb.

EXAMPLE 3: A derrick (see Figure 4) has a 10 m boom weighing 1300 kg. A load of 4000 kg hangs from the end of the boom. A cable supports the boom 2 m from the end and pulls at a 30° angle below the horizontal, the center of gravity of the boom is 4 m from the lower end. Find the horizontal and vertical reactions at the lower end of the boom and the tension in the cable. The boom makes as 45° angle with the horizontal.

Figure 4



Choose the lower end of the boom as the fulcrum to eliminate V and H from the third equation.

1. H = T cos 30°

2. V = 4000 + 1300 + T sin 30°

3. (1300 x 4 cos 45°)+(4000 x 10 cos 45
= (T·8 cos 15°)

Note the lever arm for T is from the lower end of the boom (fulcrum) to point B in space to the left of the mast. Study the diagram to see how the magnitude of its lever arm is determined (8 cos 15°)
Solving:

T = 4140 kg
H = 3580 kg
V = 9440 kg

This problem could have been solved by writing the third equation in terms of the horizontal and vertical components of the tension which would have been:

$$(1300 \times 4 \cos 45°) + (4000 \times 10 \cos 45°) + (T \times 8 \sin 30° \cos 45°) = (T \times 8 \cos 30° \cos 45°)$$

PROBLEMS

Module M 4 STATIC EQUILIBRIUM

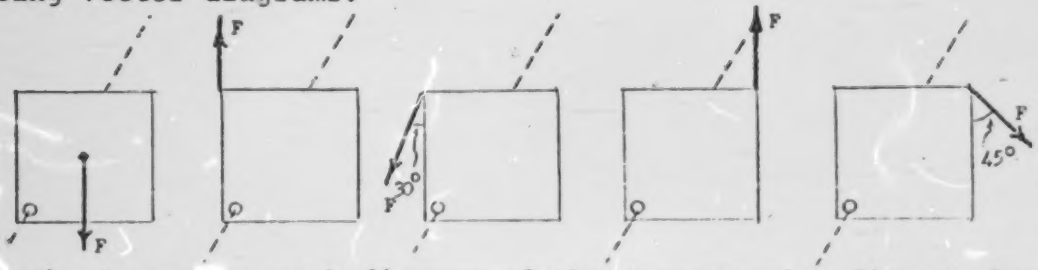
1. Why is a truck piled high with hay more likely to upset on a hillside than one loaded with the same weight of a more dense material such as crushed rock? Explain using vector diagrams.

2. A force of 40 lb is applied perpendicular to a wrench handle which is 16 in long. What torque is applied? If the force were applied at an angle of 60° to the handle, what is the torque?

3. A spring balance "weighs" up to 2000 g. How could you use it and a meter stick to find the mass of a 10 000 g object?

4. What advantage does an automobile brake drum with a large diameter have over one with a small diameter?

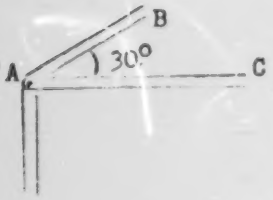
5. A full oil drum is tipped to one side. Its diameter is 18 in and its height is 32 in. What is the smallest angle the drum's axis can make with the horizontal without falling over? Explain using vector diagrams.



6. Is the torque on each diagram of the accompanying figure clockwise, counter-clockwise, or zero?

7. If the squares in problem 6 are each 2 ft on a side and the force is 10 lb in each case, calculate the torque for each.

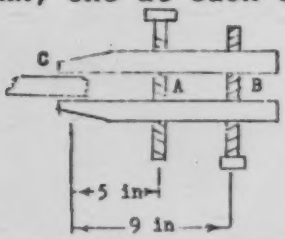
8. Trusses are used in such structures as TV towers, truck frames, and large roofs. The force in each member of a truss must be found so the member can be made large enough to carry the load in it. These forces can be found by determining the forces acting on the pin at each joint. Tensile forces pull and compressive forces push on the joint. Find the forces (magnitude and direction) in members AB and AC if the compressive force in AD is 10 000 N. Note that these forces are concurrent.



9. A 175 lb mason is 6 ft from one end of a uniform 25 ft scaffold that weighs 120 lb. Several cement blocks that weigh 100 lb are centered 9 ft from the same end. Calculate the reactions on each of the end supports.

PROBLEMS CONTINUED

10. A 90 lb bag of cement is placed on a 12 ft uniform plank 5 ft from one end. The plank weighs 45 lb. Two men pick up the plank, one at each end. How much weight does each man carry?

11. 

If the parallel wood clamp is exerting a force of 120 lb at C, find the forces in the two screws at A and B on the upper jaw. Assume the jaws are parallel.

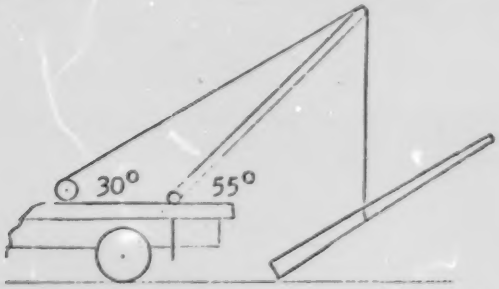
12. A 16 ft I beam is supported by columns at each end. A chain hoist is attached and can move along the beam on rollers. If the hoist and load combined is 1200 lb and is located 7 ft from one end, find the reactions on the column. The beam is uniform and weighs 1040 lb.

13. A 14 ft ladder is being used to gain access to the roof of a house. It makes an angle of 60° with the horizontal. Its center of gravity is 6 ft from the base and it weighs 70 lb. A carpenter who weighs 185 lb is momentarily stopped 9 ft from the base. Assume the wall of the house is frictionless so the reaction is horizontal. Find the reaction on the wall and the horizontal and vertical components of the reaction on the base.

14. The gate at the entrance of a lumber yard has a tubular frame and is covered with fencing. It is uniform and weighs 530 lb. It is 9 ft high and 12 ft long and has hinges 1 ft from the top and 1 ft from the bottom. Find the horizontal and vertical components of the force exerted on the gate by each hinge if the lower hinge carries three-fifths of the weight.

15. A uniform metal sign on the front of a lumber yard is 4 ft high and 8 ft long and weighs 140 lb. The inside top corner is held to the wall by a horizontal pin and by a guy wire which is fastened to the outer top corner and runs to a point 5 ft above the pin. Calculate the tension in the guy wire and the horizontal and vertical components of the force on the pin.

16. A uniform, truck-mounted, power boom is used to lower a culvert into place. It is 40 ft long and weighs 2800 lb. It makes an angle of 55° with the horizontal. The supporting boom cable makes an angle of 30° with the horizontal. It supports the culvert which weighs 3100 lb. Calculate the tension in the support cable and the horizontal and vertical components of the force on the hinge pins at the bottom of the boom.



PROBLEM ANSWER KEY

Module M 4 STATIC EQUILIBRIUM

1. Higher center of gravity. Line of action of weight moves outside wheels at small tilt angle.
2. 53.3, 46.2 ft lb
3. Place spring near pivot.
4. Braking force has larger lever arm.
5. 29.4°
6. cw, o, ecw, ccw, cw
7. 10, 0, 10, 20, 28.3 ft lb
8. 20 000 N downward along member, 17 300 N to the right.
9. 257, 138
10. 75, 60
11. 270, 150
12. 1195, 1045
13. F = 86.0, H = -86.0, V = 255
14. Upper: V = 212, H = -454, Lower: V = 318, H = 454
15. T = 132, H = 112, V = 70
16. T = 6110, H = 5540, V = 8480

EXPERIMENTS

Module M 4 STATIC EQUILIBRIUM

PURPOSE: The purpose of this experiment is to study non-concurrent, parallel, coplanar systems of forces acting on a rigid body and to study and measure the location of the center of gravity of a rigid body.

CAUTIONS:

1. Read all the instructions before handling any of the pieces of equipment.
2. Never interfere with an experiment someone else is performing or with the equipment they are using. Horseplay is never appropriate in a laboratory situation.
3. Observe all cautions listed in the procedure section of these instructions.

EQUIPMENT: Check to see if all the following equipment is available before you start.

1. One meter stick
2. One slotted weight with clamp (Welch #1154H)
3. Two lever knife-edge clamps (Welch #0745)
4. Two 100 gram knife-edge weights (Welch #0743E-36)
5. One 50 gram knife-edge weight (Welch #0743E-30)
6. One dial spring scale (2000 gram)
7. Two supports with grooves for knife-edge clamp (Welch #0743C)

PROCEDURE:

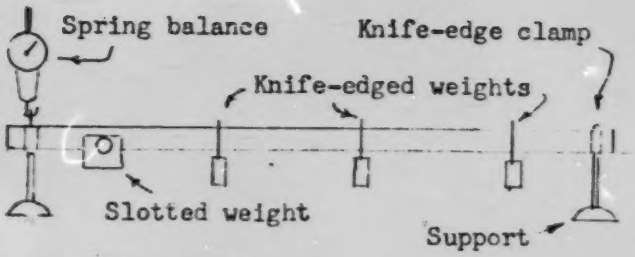
1. Weigh the knife-edge clamps and record on the data sheet.
2. Mount the knife-edge clamps at the 30 cm and 90 cm marks on the meter stick. The pointer on the clamps indicate the exact setting.
3. Mount the sliding weight at approximately the 15 cm mark on the underside of the meter stick.
4. Place the meter stick so the knife-edge rests in the grooves of the supports. Place a 100 g knife-edge weight at about the 80 cm mark to hold it down.
5. Place the other 100 g and the 50 g knife-edge weights between the supports.
6. Record the exact position of the knife-edge weights in the table on the data sheet.

CAUTION: A slight jar will cause the knife-edge weights to move so be sure to check their position each time a measurement is made.

NOTE: The object of this experiment is to find the center of gravity and the weight of the meter stick-slotted weight combination excluding all other weights and clamps.

PROCEDURE CONTINUED

7. Attach a dial spring balance to the wire stirrup of the knife-edge clamp near the slotted weight.



8. Lift the balance until the meter stick just raises off the support. Record the spring scale reading.

9. Subtract the weight of the knife-edge clamp and record the reaction (R_1) in the table. Refer to the accompanying diagram.

10. Repeat problems 8 and 9 for reaction R_2.

11. Calculate the location of the center of gravity (x) and the weight of the meter stick-slotted weight combination using the laws of equilibrium (see text). Record this information on the data sheet.

12. Remove all clamps and weights except the slotted weight from the meter stick.

13. Weigh the meter stick-slotted weight combination with the spring scale.

14. Compare calculated weight and measured weight. Record the percentage of error.

15. Attach a knife-edge clamp, sliding it back and forth until it balances when supported (in your hand) by the wire stirrup.

16. Compare the measured and calculated positions of the center of gravity. Record the difference in millimeters.

Applied Physics Module

SOUTHEAST COMMUNITY COLLEGE—Milford Campus Milford, Nebr. 68405

Module: M 5

Title: MOVIN' ON (Motion)

Module Contents:
1. Displacement, velocity, and acceleration
2. Constant velocity motion
3. Accelerated motion
4. Acceleration of gravity and vertical motion

Program: This module was produced especially for students in:
1. Surveying and Drafting
2. Architectural technology
3. Building construction technology

Purpose: The purpose of this module is to study linear motion-motion along a straight line in which no more than one reversal of direction takes place. The movement of the hammer of a pile driver is one example of such motion. Other examples are: The raising and lowering of elevators, moving conveyors, moving men and equipment to the job and raising and lowering of beams and culverts into place.

This module is prerequisite for other modules that describe force, energy, etc.

Producer: Gene Waring

Date Produced: August 1976

This project was performed pursuant to a grant from the State Board of Vocational Education through the Nebraska Research Coordinating Unit using federal funds made available under Public Law 90-576 part C, Research.

STUDENT INSTRUCTIONS

Module M 5 MOVIN' ON (Motion)

OBJECTIVES

When you have satisfactorily completed this module you will be able to:

1. Define the words: displacement, velocity, average velocity, and acceleration, state the symbol that represents each, and state the British, mks and cgs units of each.
2. Convert units of velocity from one measuring system to another.
3. State the four equations that describe uniform accelerated motion.
4. Solve various constant velocity and average velocity problems.
5. Solve various problems of uniform accelerated motion, including those involving deceleration and vertical motion; and including those in which one change in direction might take place.

In order to satisfactorily complete this module, you must pass a test consisting of true-false, multiple choice, and problem-type questions based on the objectives listed above with a grade of at least 80%.

SELF-EVALUATION TEST

Perhaps you have had previous experience with the study of motion. You may feel that your experience will enable you to perform most of the tasks listed in the objectives section above. A self-evaluation test (or sample test) is included in this booklet (pink paper, page 5) along with an answer key. You can evaluate your previous knowlege of the subject by taking this test (under normal test conditions) before you perform any of the learning activities listed below.

The result of this test is an indication of your knowledge. If you can answer all questions correctly, you may not need additional study. However, you should proceed with the learning activities if you can't answer all questions, correctly. The answer key page (pink, page 6) directs you to various learning activities.

Before you take the instructor-graded test (post-test), read the "test" section at the end of these instruction pages (white paper, page 4).

LEARNING ACTIVITIES

The following list of activities is designed to help you achieve the objectives of this module. You are not required to complete all of the activities. They are intended to supplement your previous knowledge of the subject. If you wish, your instructor will recommend the learning activities you should complete.

I. Reading: The chapters, sections and page numbers are given for several textbooks. You may select your own textbook and the information sheet that is included in this booklet. As you read, keep the list of objectives handy. Write down on separate paper a list of the definitions, laws, principles, formulas, etc., that the objectives refer to. This list will be very useful as an aid to memorizing them.

A. Information Sheet. Read the information sheets included in this booklet. They are printed on green paper, (page 7). The information sheets cover subject matter that is presented only briefly or not at all in the textbooks.

B. Introductory Applied Physics, Harris, N.C., Hemmerling, E.M., McGraw-Hill, 3rd ed., 1972. Read part of chapter 3, pages 43-59.

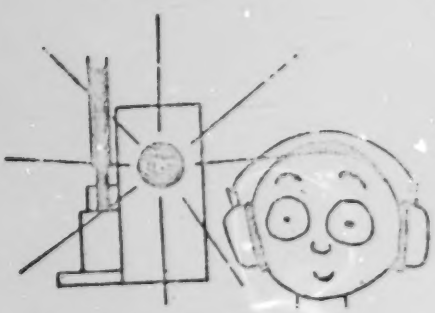
C. Elements of Physics, Smith, A.W., Cooper, J.N., McGraw-Hill, 8th ed., 1972. Read part of chapter 5, pages 49-55.

D. Physics for Career Education, Ewen, D., Nelson, R., Schurter, N., McFadden, L., Prentice-Hall Inc., 1st ed., 1974. Read all of chapter 3, pages 29-38 and all of chapter 5, pages 47-53.

E. Physics for Technology, Betts, J., Reston Publishing Co. Inc., 1st ed., 1966. Read part of chapter 3, pages 23-37.

F. Modern Technical Physics, Beiser, A., Cummings Publishing Co. Inc., 1st ed., 1966. Read all of chapter 3 and part of chapter 4, pages 35-54.

II. Listening/Viewing: The following single-concept film loops (8 mm) are available in the Learning Resource Center (LRC). There is a brief training session given by the LRC staff to familiarize you with the projection and sound equipment (Viewlex 702 or Technicolor) and must precede the viewing of the films. Ask the LRC personnel about this training.



A. How an Air Track Works (BFA Ealing 80-280)
B. Constant Velocity and Uniform Acceleration (BFA Ealing 80-272)
C. One Dimensional Motion (BFA Ealing 80-300)
D. The Velocity Vector (BFA Ealing 80-251)
E. The Acceleration Vector (BFA Ealing 80-253)
F. Velocity and Acceleration in Free Fall (BFA Ealing 80-256)
G. Acceleration Due to Lunar Gravity (AAPT/NASA Films -20)

III. Solving Problems: Solve the problems in the problem set in this booklet. They are printed on ivory paper. Answers are given for each problem. Work as many of them as you feel are necessary to gain competence in solving motion problems.

IV. Solving Problems (Optional) Solve some of the problems at the end of the chapter in your textbook. These are for additional practice if you feel it is needed and are mostly general interest problems.

V. Performing Laboratory Experiments: There are two experiments in this module. One experiment covers uniform velocity; the other covers uniformly accelerated motion. Both experiments are performed on an air track.

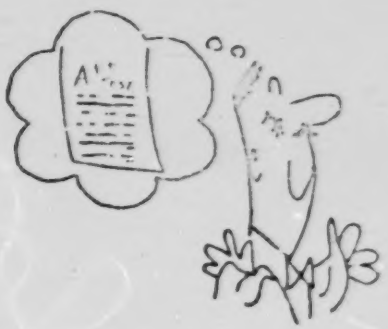
Read the laboratory instructions in the booklet (yellow paper, page 13) and pay particular attention to the cautions given. Obtain a laboratory data sheet (M-5) and the equipment from the instructor. Keep this booklet open to the instruction pages and proceed step by step with the experiment.

TEST

You may proceed with the test at any stage of your study of this module; obtain a copy of the test, answer all questions and return it to your instructor.

A grade of 80% is required for satisfactory completion of the module. A grade lower than 80% will require that you repeat the test. You must show evidence of further study before you repeat it, however. (Hand in your papers on problem solving, lab reports, etc.)

Every test you take on this module will be averaged to determine your module grade. Don't take the test until you have adequately prepared yourself to meet the requirements listed in the objectives section. Instead, go to the learning activities.



SELF-EVALUATION TEST

Module M 5 MOVIN' ON (Motion)

Read each question carefully and decide which one of the answers is best. Notice what letter your choice is. Then, on separate paper, write the problem number followed by the letter you chose. Take the test under normal test conditions; without help from other people and without references. The answer key is on the following page.

T - F 1. A screwdriver dropped from rest will fall four times as far in 2 s as it does in 1 s.

T - F 2. An automobile having a speed of 55 miles per hour travels 240 miles in 4 hr.

T - F 3. The downward acceleration of a metal ball depends on whether it was thrown upward or thrown downward.

T - F 4. An elevator moving upward comes to a stop. Its acceleration is downward.

T - F 5. The acceleration of gravity is 3.2×10^2 ft/s^2.

6. An automobile goes from 15 miles per hour to 55 miles per hour with uniform acceleration. Its average velocity is:

a) 30 mi/h
b) 40 mi/h
c) 35 ft/s
d) 51.3 ft/s

7. A car has an initial velocity of 40 ft/s and an acceleration of -4 ft/s^2. In 10 s it travels how many feet?

a) 100
b) 200
c) 360
d) 300

8. Sixty miles per hour is equivalent to:

a) 96.1 km/h
b) 44 ft/s
c) 66 ft/s
d) 37.5 km/h

9. If an elevator can accelerate at 3 m/s^2 to a maximum speed of 4.3 m/s, how far upward will it go in 10 s starting at rest?

10. Find the displacement after 4 s of a steel ball thrown vertically upward with an initial speed of 90 ft/s. Is it still going upward or is it on the way back down?

ANSWER KEY TO THE SELF-EVALUATION TEST

Module M 5 MOVIN' ON (Motion)

Question-Answer	If you missed this question, you are directed to these learning activities
1. T	I. Reading or II. Listening/Viewing
2. F	III. Solving Problems V. Laboratory Experiments
3. F	I. Reading
4. T	I. Reading or II. Listening/Viewing
5. F	I. Reading
6. d	I. Reading III. Solving Problems
7. b	III. Solving Problems V. Laboratory Experiments
8. a	III. Solving Problems
9. 39.9 m	III. Solving Problems V. Laboratory Experiments
10. 104 ft ↓	III. Solving Problems V. Laboratory Experiments

INFORMATION SHEET

Module M 5 MOVIN' ON (Motion)

Study the table below which lists the four formulas for constantly accelerated motion. Note that in the four formulas there are five

	FORMULA	SYMBOL OMITTED
1	$a = \frac{v - v_0}{t}$	s
2	$s = \frac{(v + v_0)}{2} t$	a
3	$v^2 = v_0^2 + 2as$	t
4	$s = v_0 t + \frac{1}{2} at^2$	v

quantities: time (t), displacement (s), initial velocity (v_0), final velocity (v), and acceleration (a). Note, also, that one quantity is missing from each equation, but, that the initial velocity is found in all four.

Mathematically speaking, only two of the four equations are unique. The third and fourth equations can be derived from the first two (for example) by eliminating other variables. All of this means that you can solve for only two unknown quantities and that the other three must be given in the problem.

Sometimes it is not readily apparent in a problem that three quantities are given (or known). You must keep in mind, however, each of the four equations contains four quantities. Three must be given in order to solve for the fourth. Some statements and their meanings are:

1. "An object starts from rest" means $v_0 = 0$
2. "A body comes to a stop" means $v = 0$
3. "The beginning speed is 25 mi/hr and the speed doubles" means $v = 50$ mi/hr
4. "A falling body . . ." means $a = -32$ ft/s^2 or -9.8 m/s^2
5. "A body thrown upward returns to its starting point" means $s = 0$
6. "How high does an object go . ." means $v = 0$

There are four quantities in each of the four formulas. None contains the same set of four quantities. Thus, with three given and one unknown, you really have no choice in finding the solution. Only one equation will work!

After you have evaluated the fourth quantity, things get easier. The fifth quantity can now be found by using any one of the remaining three equations. Choose, by inspection, the simplest of the three.

The following examples will illustrate the above points:

EXAMPLE: An automobile decelerates at 12.6 ft/s^2. If the initial velocity is 55 mi/hr, how much time does it take to get stopped and how far does it travel?

SOLUTION:

1. Since displacement, velocity and acceleration are vectors, we should first assign positive and negative directions (you can usually do this mentally). Choose the forward direction as positive.
2. Make a list of knowns. $a = -12.6\ ft/s^2$; $v_0 = +80.7\ ft/s$; $v = 0$; $t = ?$

   From this list it is easy to see that equation 1 is the only one we can use since all others have displacement (s) in them, and we do not know its value.
3. Solve equation 1 for time: $t = (v - v_0)/a$
4. Substitute the numbers and evaluate:

$$t = \frac{0 - 80.7\ ft/s}{-12.6\ ft/s^2} = 6.4\ s$$

5. Equation 2 appears, at first glance, to be the easiest to use for solving for distance:

$$s = \frac{(0 + 80.7\ ft/s)}{2}(6.4\ s) = 258\ ft$$

EXAMPLE: A hammer is thrown at 30 m/s. Where is it 5 s later and what is its velocity?

SOLUTION:

1. Take upward as positive.
2. List: $a = -9.8\ m/s^2$; $v_0 = +30\ m/s$; $t = 5\ s$; $s = ?$
3. Choose equation 4, substitute and evaluate the displacement:

$$s = v_0 t + \tfrac{1}{2} at^2 = (30\ m/s)(5s) + \tfrac{1}{2}(-9.8\ m/s^2)(5s)^2$$

$$= 150\ m - 123\ m$$

$$= +27\ m$$

4. Choose equation 1, solve, substitute and evaluate the velocity:
   $v = v_0 + at = 30\ m/s + (-9.8\ m/s^2)(5s) = -19\ m/s$

FALLING BODIES

Falling bodies are normally moving through air, near the surface of the earth. Except in a near vacuum, there are several forces besides the pull of gravity. They are:

1. Friction: Depends on the speed and shape of the object. It increases as the object goes faster and faster. It is always in a direction opposite to that of the motion.

2. Buoyancy: Depends on the density of the air. It is usually negligible except on low density objects such as balloons. It is always upward.

3. Bernoulli forces: Depends on air flow around the object and causes sideways pressure. The fluttering of the leaves as they fall is one example.

4. Gravity: Depends on distance between the center of the earth and the center of the object. It may depend on local variations of gravity. Its direction is always downward.

5. Magnetic forces: If an object becomes electrically charged as it falls, the Earth's magnetic field could cause a sideways deflection.

At the beginning of free fall, gravity is the overriding force except on balloons and other light objects. When the speed increases friction also increases, partially cancelling the pull of gravity. At faster and faster speeds friction increases until it equals the pull of gravity. During this time the acceleration decreases gradually to zero and the object falls at a constant speed (terminal velocity) from then on. On some objects the other forces may be important.

Different objects fall for different times during the transition and attain different terminal velocities. The four equations of motion for falling bodies give correct results for a few seconds for most fairly dense objects. A skydiver, for example, falls 16 ft during the first second, the same as predicted by equation 4. He falls 6 ft short of the 144 ft predicted by the equation at the end of the 3rd second (4.3% error).

A skydiver falls face downward, arms and legs spread. With his parachute and floppy clothes, he is a falling object that offers a lot of resistance to motion. He reaches a terminal velocity of 174 ft/s at the end of 11 s. Other objects offering less resistance may fall several seconds with almost no deviation in the distance and speed as predicted by the equations. A 5 in polished metal sphere, for example, will fall more than a minute before reaching terminal velocity. The terminal velocity would be over 350 ft/s and the sphere would have fallen more than a mile before reaching it.

The above information is to give you an indication of when the equations give correct results. The problems in the problem set are realistic within small percentage errors.

PROBLEMS

Module M 5 MOVIN' ON (Motion)

1. Explain the relationship among an object's initial, final and average velocities if the motion is (a) uniform velocity, (b) uniform acceleration.

2. Give an example of the circumstances when an object can have (a) a velocity but no acceleration, (b) an acceleration but no velocity.

3. A wrench thrown vertically upward is accelerated by gravity before it reaches its peak, at the peak and on its way back down. Explain the difference between the expressions: "instantaneous zero velocity", "an object at rest or stopped." What is the acceleration and velocity at the peak of the flight?

4. A road construction crew on its way home after a long day's work traveled 5.5 mi in 8.3 min. What is the average speed in miles per hour? If the same average speed is maintained, how much time is required to travel the remaining 14.5 mi back to town?

5. An architectural draftsman traveled 4 blocks north (from his residence),), then 7 blocks east, then 2½ blocks north on his way to work. If it took him 11.4 min (including stops; one at a stop sign and one traffic light), find his displacement, distance traveled, average speed, and average velocity. (Assume 10 blocks equal 1 mi)

6. A belt sander has a surface speed of 310 ft/s. How far does a point on the belt go in 5 min? How long does it take to travel 1 mi?

7. A band saw (for wood) has a surface speed of 800 ft/min. If the blade has 8 teeth per inch, how many teeth move past the cutting table in 5 min. How much time is required for 1000 ft of the blade to move past the cutting table?

8. A conveyer that moves sand and gravel to the top of a screener travels at 1.5 ft/s and carries about 40 lb/ft. How many tons of gravel can be moved in one hour?

9. The television transmitter tower of KOLN-TV, Beaver Crossing, Nebraska, room is 11250 ft above ground level. The elevator can go 150 ft higher to the base of the transmitter antenna. How long does it take for a round trip from the ground to the antenna and back? The speed on the upward trip is 1.1 ft/s, and the downward speed is 1.4 ft/s. What is the average speed for the round trip? (Assume no stop time before returning)

10. An elevator in a new building goes to the 10th floor, 45 m high, of a building under construction. If the elevator accelerates (and decelerates) at 4.3 m/s^2 to a maximum speed of 3 m/s, find the time required to go to the 10th floor from ground level.

PROBLEMS CONTINUED

11. A surveying crew returning to the maintenance yards from a job, was traveling 55 mi/h. As they came to a railroad crossing, the driver noticed a train approaching. He applied the brakes at a point 225 ft from the crossing. The deceleration was 15 ft/s^2. Was he able to avoid a collision?

12. The hammer of a pile driver is raised 5.2 m and released. What is its velocity when it hits the piling? How much time is required for the hammer to fall that distance?

13. A bridge crew was returning home from a long day on the job. They were going 50 mi/h as they crested a small hill. A farm tractor going 8 mi/h in the same direction approached a narrow bridge. The driver first noticed the tractor when he was 210 ft away. Allow 0.75 s reaction time and a deceleration of 12.5 ft/s^2. Was he able to stop in time?

14. A field technician doing some testing on a bridge structure was working from a man-lift when he lost his balance. In the act of catching himself, a pocket calculator was thrown straight upward at a velocity of 15 m/s. It took 4 s for the calculator to hit the ground after just missing the man-lift on its way down. What was its speed when it hit the ground? How high was the man-lift above the ground?

15. A crane is lowering a beam on a bridge into place at a speed of 2.2 m/s. If the braking system decelerates, the beam at 3.1 m/s^2 how far above the supports must the operator apply the brakes in order to stop the beam 2 m above the supports?

ANSWER KEYS (PROBLEM)

Module M 5 MOVIN' ON (Motion)

1. a) same, b) $V_{av} = (v + v_0)/2$

2. a) car moving on level ground at 55 mi/h
   b) object thrown straight up at peak of flight

3. a) v = 0 at a specific instant
   b) v = 0 for a period of time no matter how small
   c) zero

4. 39.8, 21.9 s

5. 0.955 mi at 42.9° N of E, 1.35 mi, 7.11 mi/h, 5.03 mi/h at 42.9° N of E

6. 93 000 ft, 17.0 s

7. 32 000, 75 s

8. 108

9. 21.2 min, 16.7 min, 1.23 ft/s

10. 15.3 s

11. Yes, 8 ft from the crossing

12. 10.1 m/s, 1.03 s

13. Yes, car travels 55 ft during reaction, 215 ft during deceleration, but tractor moves 77.6 ft, car stops 18 ft from tractor.

14. -24.2 m/s, 18.4 m

15. .781 m

EXPERIMENTS

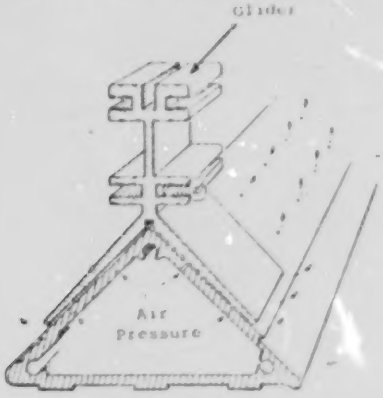
Module M 5 MOVIN' ON (Motion)

PURPOSE: The purpose of these experiments is to study linear motion on an air track. Constant velocity and constantly accelerated motion are studied. The acceleration of gravity is measured in the second experiment.

CAUTIONS:

1. Read all of the instructions before handling any of the equipment.
2. The Basic Spark Source can cause deep painful burns as well as shock. Read and follow the instructions carefully.
3. Observe all cautions in the procedure section of these instructions.
4. Never interfere with an experiment someone else is performing or with the equipment they are using. Horseplay is never appropriate in a laboratory situation.

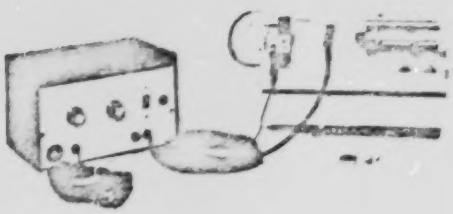
INFORMATION: A linear air track is used in both experiments. It is a simple device which allows you to observe motion in which there is almost negligible friction. Glides are supported so they "float" and move on a cushion of air produced by blowing air with a vacuum cleaner out of small holes on the track. The viscosity of the thin layer of air between the glider and track is the only source of friction.



* Fig. 1 The air track

The air track is a precision device. Distances along the track can be measured to the nearest millimeter. The timing measurements needed for studying motion are made with a timing device that generates high voltage pulses at regular intervals. The resulting spark holes recorded on spark paper make a record of the position of the glides each time without affecting the motion of the glider. You should view film A (See Listening/Viewing, page 3) before proceeding with the experiment.

EQUIPMENT:



* Fig. 2 Basic Spark Source

1. Student 1.2 m air track (Ealing 33-1512)
2. Two stage blower - 115 v (Ealing 33-0167)
3. Various blower hoses, couplings, tees, manifolds, etc.
4. Basic spark source - 60 Hz (Ealing 33-2403)
5. Spark tape (Ealing 33-0274)

Check to see that all equipment is available before you start. Ask your instructor if you have any questions about the equipment.

PROCEDURE:

CAUTION: Do not plug in the basic spark source until you are ready to use it. See step 14 below. Shocks from this spark source can burn small, deep, and very painful holes in your skin. Other injuries can occur as you react to the shock. BE EXTREMELY CAREFUL NOT TO TOUCH THE SPARKING WIRE when the spark source is attached.

CAUTION: Be careful not to drop the glides. Dropping them from even a few inches height will probably ruin them. To avoid damaging surfaces, do not slide the glides on the track with the air suppy shut off.

1. Attach the air hose from the vacuum cleaner to the air track.

CAUTION: Keep the air hose on the back or side of the table so it will not be bumped. It could drag the air track off the table.

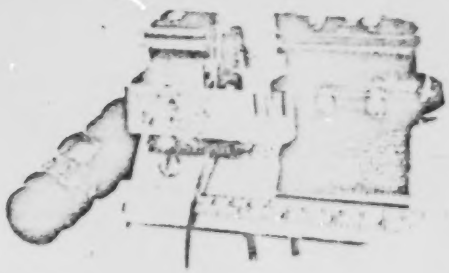
2. Plug in the air supply (vacuum cleaner) and turn it on. If only one track is being used, remove one rubber stopper from the manifold on top of the air supply. The entire supply is not needed for one track.

LEVEL THE AIR TRACK

3. Remove all gliders except one. Place one glider near the center of the track. If the track is level, the glider will not accelerate in either direction. Turn the adjusting screw knob on the air supply end of the track. Note: Slight adjustments make large changes in the glider's motion.

CAUTION: Do not bump or jar the track once it is leveled. Small irregularities in the table top will have a large effect on the gliders motion if the track is moved. Naturally, you should also avoid bumping or jarring the table for the same reason.

4. Place the gliders on the track and observe their motion including collisions with the spring bumpers. DO NOT LAUNCH THE GLIDERS WITH EXTREME VELOCITIES.



* Fig. 3 Rubber band launcher

5. Attach a rubber band to the rubber band launcher (see Figure 3). Remove all but one glider.

6. Practice launching the glider. You can vary the speed by placing the rubber bank in different slots. To reproduce the same velocity, always push the glider back until the spring bumpers just touch. Hold the glider with one finger on top. Release suddenly. Try this with both large and small gliders. Avoid touching

the spark wires. Assume it is hot even though the spark source is not attached yet.

7. Shut off the blower during set-up time.

8. Insert a strip of spark paper in the groove on the back side of the air track. A 120 cm length is sufficient.

9. If a transfer wire is not attached to the nylon post on one end of the gliders, wrap one turn of copper wire around the post and tighten. Bend the wire in the shape shown in Figure 4.

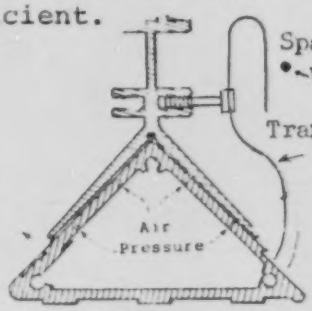


Fig. 4

NOTE: The transfer wire is vertical, near the sparking wire so it will not matter if the sparking wire sags a little. The bottom end of the transfer wire is placed near the upper edge of the spark paper. By bending the wire downward, more than one run can be made on one strip of paper.

10. Turn the blower on and move the glider slowly along the track. Check to see that the transfer wire does not touch the sparking wire or the spark paper. The gaps at both places should be as small as you can make them without rubbing. The sum of the two gaps should not exceed 1 cm anywhere along the track. Rubbing at either place will alter the motion of the glider.

EXPERIMENT A "Constant Velocity"

11. You are now ready to attach the Basic Spark Source. USE CARE! OBSERVE ALL CAUTIONS.

12. Attach the alligator clip leads to the air track (See Figure 2)
    a) Attach the large wire (hot) with the red lead to the sparking wire near the rubber band launcher.
    b) Attach the small wire (ground) with the black lead to the end stop near the rubber band launcher.

13. Set the Timing Source Selector on the 10.0 Hz position. Note that the sparks will occur 0.1 s apart.

14. You may now plug in the Basic Spark Source but observe the following cautions:

CAUTIONS

1. Use the spark source only when recording. Do not fire it longer than necessary.
2. Never push the remote operate button without insuring a proper gap; in such a case, the discharge energy will occur internally. Continued operation without a proper gap (See Step 10) will damage the electronic components within the unit.

3. Unplug all spark sources when making lead changes; BE SAFE, assume the unit will misfire.

15. You are now ready to make your first recording:
    a) Push the glider against the rubber band to get ready for launching. The rubber band should be in the position that gives the glider its greatest launch velocity.
    b) Simultaneously, release the glider and depress the remote operate button on the spark source.
    c) Be sure to turn off (release) the remote operate button as soon as the glider reaches the opposite end of the track to avoid making spark holes on the return trip and confusing the record.

16. Unplug the spark source. BE SAFE!

EXPERIMENT B "Constant Acceleration"

17. Without moving the air track along the table, lift the air supply end of the track and place a one-fourth inch block under the single leg.

18. Bend the transfer wire down so the spark will record marks near the bottom edge of the spark paper. Test for a proper gap along the whole length of the track.

19. Remove the rubber band from the launcher.

20. Plug in the Basic Spark Source.

21. You are now ready to make your second spark record.
    a) Push the glider back so spring bumper just touches the bumper on the end stop.
    b) Simultaneously release the glider and depress the remote operate button on the spark source.
    c) Be sure to turn off (release) the remote operate button as soon as the glider reaches the opposite end of the track to avoid making spark holes on the return trip and confusing the record.

22. You now have a record on spark paper for both experiments. Unplug the equipment and put it away.

23. Tape the spark paper to a table and lay a meter-stick on it edgewise so the markings are adjacent to the spark holes. Do <u>not</u> place the end of the meterstick on the first hole. Instead, put the one centimeter mark on the first hole and subtract it from all successive readings. Ignore the spark holes made when the rubber band was still in contact during launch.

24. Record the position of the holes for both experiments in the proper place on the data sheet.

25. Plot the data for experiment A on graph paper.

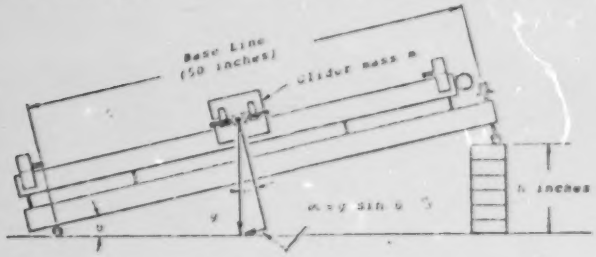
26. Calculate the speed during the first and last intervals. Does friction play a significant part during short runs on the air track? By what percentage did the velocity decrease?

27. Plot the data for experiment B on graph paper.

28. Calculate the average velocity for each interval. The average velocity for a given interval is the instantaneous velocity at the mid-point of the interval.

29. Calculate the acceleration from the mid-point of one interval to the mid-point of the next interval for each successive interval. Record in the table: $a = (v - v_0)/t$

30. Average the accelerations you have listed in the table. Note: the acceleration is shown as a vector in Figure 5. The acceleration of gravity is also shown. The sine of this angle is the ratio of height h in inches to the base line in inches (50 in).



* Fig. 5 Vector diagram

31. Calculate the sine of the angle.

32. Calculate the acceleration of gravity. $g = a/\sin\theta$.

33. Look up the standard value of the acceleration of gravity in your text.

34. Calculate the percentage difference in you calculated value and the standard value of the acceleration of gravity.

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Applied Physics Module

SOUTHEAST COMMUNITY COLLEGE – Milford Campus Milford, Nebr. 68405

Module: M 6

Title: Friction

Module Contents:
1. The nature of friction
2. The coefficient of friction
3. Kinetic and static friction
4. Angle of repose
5. Rolling friction
6. Lubrication

Program: This module has been prepared especially for students in:
1. Surveying and drafting technology
2. Architectural drafting technology
3. Building construction technology

Purpose: The purpose of this module is to introduce the concept of friction. It is a force that always acts to impede motion. It reduces efficiency of machines and great efforts are made to minimize it by using lubricants and wheels. Sometimes friction is desirable; the action of brakes and clutches depend on it. Friction is an ever present force. It is essential that you understand the nature of friction.

Producer: Gene Waring

Date Produced: September 1976

This project was performed pursuant to a grant from the State Board of Vocational Education through the Nebraska Research Coordinating Unit using federal funds made available under Public Law 90-576 part C, Research.

STUDENT INSTRUCTIONS

Module M 6 FRICTION

OBJECTIVES

When you have completed this module satisfactorily, you will be able to:

1. Define friction, coefficient of friction and normal force.
2. State the laws of friction for dry surfaces.
3. State the mathematical formula relating the force of friction, normal force and coefficient of friction. State the formula for calculating the normal force on an inclined plane.
4. Define the angle of repose (angle of uniform slip) and state its relationship to the coefficient of friction.
5. State the differences between limiting friction and kinetic friction.
6. State two ways in which rolling friction differs from sliding friction.
7. State the effects of lubricants on sliding and rolling friction.
8. List rolling, sliding and fluid friction in order of decreasing friction effects.
9. Solve various frictional problems, including those on an inclined plane, in which the relationships in objectives 3 and 4 are involved.

In order to satisfactorily complete this module, you must pass a test consisting of true-false, multiple choice, and problem type questions based on the objectives listed above with a grade of at least 80%.

SELF-EVALUATION TEST

Perhaps you have had previous experience with the study of measurement. You may feel that your experience will enable you to perform most of the tasks listed in the objectives section above. A self-evaluation test (or sample test) is included in this booklet (pink paper, page 5) along with an answer key. You can evaluate your previous knowledge of the subject by taking this test (under normal test conditions) before you perform any of the learning activities listed below.

The result of this test is an indication of your knowledge. If you can answer all questions correctly, you may not need additional study. However, you should proceed with the learning activities if you can't answer all questions, correctly. The answer key page (pink paper, page 6) directs you to various learning activities.

Before you take the instructor-graded test (post-test), read the "test" section at the end of these instruction pages (white paper, page 4).

LEARNING ACTIVITES

The following list of activities is designed to help you achieve the objectives of this module. You are not required to complete all of the activities. They are intended to supplement your previous knowledge of the subject. You may want to do most or all of the activities if your overall background requires it. If you wish, your instructor will recommend the learning activities you should complete.

I. Reading: The chapters, sections and page numbers are given for several textbooks. You may select your own textbook and the information sheet that is included in this booklet. As you read, keep the list of objectives handy. Write down on separate paper a list of the definitions, laws, principles, formulas, etc., that the objectives refer to. This list will be very useful as an aid to learning them. Also, read the information sheet (A).

A. Information Sheet. Read the information sheets included in this booklet. They are printed on green paper (page). The information sheets cover subject matter that is presented only briefly or not at all in the textbooks.

B. Introductory Applied Physics, Harris, N.C., Hemmerling, E.M., McGraw-Hill, 3rd ed., 1972. Read sections 6.8--6.17 in chapter 6, pages 144-152.

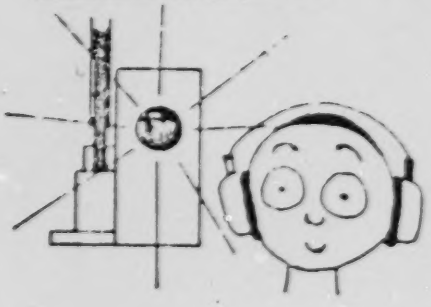
C. Elements of Physics, Smith, A.W., Cooper, J.N., McGraw-Hill, 8th ed., 1972. Read sections 3.5--3.9 in chapter 3, pages 30-33.

D. Physics for Career Education, Ewen, D., Nelson, R., Schurter, N., McFadden, L., Prentice-Hall Inc., 1st ed., 1974. Read sections 10.13--10.17 in chapter 10, pages 142-44. Also read all the information sheets (see A above).

E. Physics for Technology, Betts, J., Reston Publishing Co. Inc., 1st ed., 1976. Read all of chapter 7, pages 82-90.

F. Modern Technical Physics, Beiser, A., Cummings Publishing Co. Inc., 1st ed., 1966. Read all of chapter 6, pages 78-86.

II. Listening/Viewing: The following single concept film loops (8 mm) are available in the Learning Resource Center (LRC). There is a brief training session given by the LRC staff to familiarize you with the film loop projector (Technicolor or Viewlex 702) and must precede the viewing of the films. Ask the LRC personnel about this training.



A. Rough and Smooth, (EBE S-80781)
B. Texture, (EBE S-80782)
C. Rolling, (EBE S-80783)
D. Wheels, (EBE S-80784)

III. Solving Problems: Solve the problems in the problem set in this booklet. They are printed on ivory paper (page). Answers are given for each problem. Solve as many of them as you feel are necessary to gain competence in solving problems about friction. The problems from number five on are applied to your technology.

IV. Solving Problems (Optional): Solve some of the problems at the end of the reading set in your textbook. These are for additional practice if you feel it is needed and are mostly general interest problems.

V. Performing Laboratory Experiments: There is one experiment in this module. It will give you practice in learning about sliding friction both on flat and inclined surfaces.

Read the laboratory instructions in this booklet (on yellow paper, and pay particular attention to the cautions given). Obtain a laboratory data sheet (M - 6) and the equipment from the instructor. Keep this booklet open to the instruction pages and proceed step by step with the experiment.

TEST

You may proceed with the test at any stage of your study of this module; obtain a copy of the test, answer all questions, and return it to your instructor.

A grade of 80% is required for satisfactory completion of the module. A grade lower than 80% will require that you repeat the test. You must show evidence of further study before you repeat it, however. (Hand in your papers on problem solving, lab reports, etc.)

Every test you take on this module will be averaged to determine your module grade. Don't take the test until you have adequately prepared yourself to meet the requirements listed in the objectives section. Instead, go to the learning activities.

SELF EVALUATION TEST

Module M 6 FRICTION

Read each question carefully and decide which one of the answers is best. Notice what letter your choice is. Then, on separate paper, write the problem number followed by the letter you chose. Take the test under normal test conditions; without help from other people and without references. The answer key is on the following page.

T - F 1. The force of friction is proportional to the normal force.

T - F 2. Changing the angle of an inclined plane will not change the coefficient of friction between the incline and the object sliding on it.

T - F 3. A 195 lb weight on a 37° incline has a normal force of 117 lb.

T - F 4. Kinetic friction is usually less than limiting friction if everthing else remains the same.

T - F 5. Lubricants can reduce kinetic friction but not limiting friction.

6. Metal containers at a manufacturing plant slide down a 27.5° incline at uniform speed. The coefficient of friction is:

a) 0.462 c) 0.521
b) 0.887 d) cannot be calculated

7. A force of 250 N is required to slide a TV set across a tiled floor. If the coefficient of kinetic friction is 0.63, how much does the TV set weigh in newtons?

a) 694 c) 157
b) 397 d) cannot be calculated

8. A crate is pulled up a 23° incline on which the coefficients of limiting and kinetic friction are 0.42 and 0.28. If the crate weighs 1200 lb, what force up the incline will start the crate moving? What force is necessary to keep it moving?

ANSWER KEY TO THE SELF-EVALUATION TEST

Module M 6

Question-Answer	If you missed this question, you are directed to these learning activities
1. T	I. Reading or V. Laboratory Experiments
2. T	I. Reading or V. Laboratory Experiments
3. F	III. Solving Problems or V. Laboratory Experiments
4. T	I. Reading (Information Sheets)
5. F	I. Reading or II. Listening/Viewing
6. c	III. Solving Problems
7. b	III. Solving Problems or V. Laboratory Experiments
8. 933 lb, 778 lb	III. Solving Problems or V. Laboratory Experiments

INFORMATION SHEET

Module M 6 FRICTION

Part I

SLIDING FRICTION

For dry surfaces, friction has been found to obey the following rules:

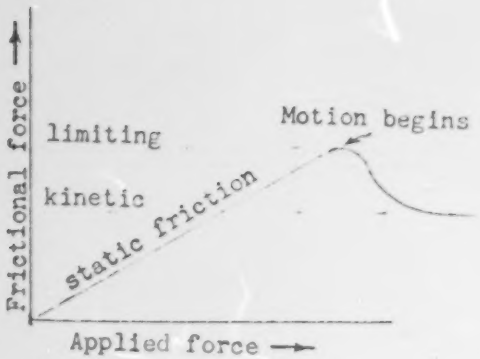


Fig 1

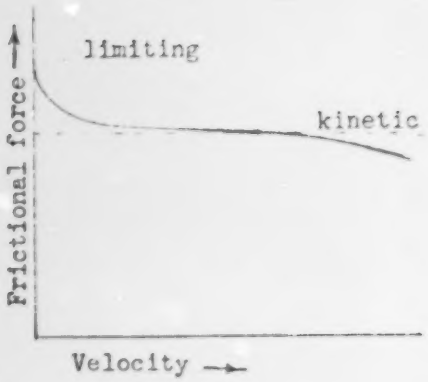


Fig 2

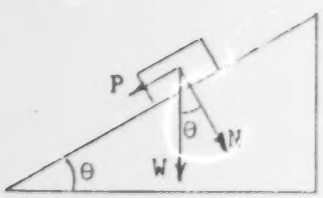


Fig 3

1. The frictional force is equal to the applied force before motion begins (see Fig. 1) and is called static friction.

2. The static frictional force is maximum just before motion begins. The maximum value of static friction is called limiting friction (see Fig. 1). Many texts use the term static friction to mean limiting friction.

3. After motion has begun, friction is usually less than the limiting friction and is called kinetic friction (see Fig. 1).

4. Kinetic friction is nearly independent of speed. It gradually decreases at higher and higher speeds, but the change is slight until extreme speeds are reached (see Fig. 2).

5. Both limiting and kinetic friction depend on the nature of the sliding surfaces.

6. Both limiting and kinetic friction depend on the force pressing the two surfaces together. This force is called the normal force (N) (see Fig. 3). On an incline the normal force is given by the equation:

$$N = W \cos \theta$$

where θ is the angle of the incline and W is the weight of the sliding object. Note that the normal force is the component of the weight that is perpendicular to the incline.

7. The frictional force is independent of the apparent contact area. The distinction between apparent and real contact area is discussed in Part II.

THE COEFFICIENT OF FRICTION

The seven rules above describe how friction works. The source or cause of friction is described in Part II.

Rule 6 states that friction is proportional to the normal force, so:

$$f = \mu N$$

Where μ is the proportionality constant and is called the coefficient of friction. The coefficient of friction depends on the nature of the two surfaces. Table 1 lists the coefficient of static friction and the coefficient of kinetic friction. For a given normal force, you can calculate the limiting or kinetic friction.

	μs	μk
wood on wood	0.5	0.3
steel on steel (smooth)	0.75	0.50
metal on metal (lubricated)	0.03	0.03
rubber on dry concrete	0.9	0.7
rubber on wet conrete	0.7	0.5
plastic on steel	0.2	0.2

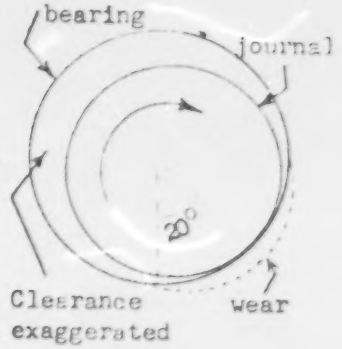
(Table 1)

EXAMPLE 1. A car weighing 4000 lb has a coefficient of limiting friction of 0.9 between tires and concrete. What is the maximum braking force that can be applied without skidding?

$f = \mu N = 0.9\ (4000\ \text{lb}) = 3600\ \text{lb}$

EXAMPLE 2. A steel shaft of a motor turns in a lubricated bronze bearing. The coefficient of kinetic friction is 0.12. A V-belt exerts a downward pull of 225 lb on the bearing. The bearing also supports 12 lb of an armature's weight. Find the frictional force and the retarding frictional torque on the 0.75 in shaft. Note that even though the forces are straight downward, the shaft tends to roll up the side of the bearing before slipping begins. Wear occurs in the dashed area, 20° from bottom dead center.

Fig 4



SOLUTION: The normal force is given by $N = F \cos \theta$

$N = 237 \cos 20° = 223$ lb

The frictional force tangent to the journal is:

$f = \mu N = 0.12(223\ \text{lb}) = 26.8$ lb

The retarding torque is (Force x lever arm):

$T = f \cdot \ell = 26.8\ \text{lb} \times 0.375\ \text{in} = 10.0\ \text{in} \cdot \text{lb}$

ROLLING FRICTION

Use of wheels, rollers, or ball bearings greatly reduces friction since, theoretically, there is no sliding friction involved. In a practical sense, however, the wheel or the surface (or both) will

flatten some under the pressure of contact. A soft wheel tends to flatten on a hard surface (automobile tire for example). Consequently, a larger surface is in contact and some sliding is involved since there will be some relative motion.

A hard wheel on a soft track (wagon wheel rolling on a muddy road for example) leaves a deep track in its path. Not only is the wheel trying to roll uphill all the time trying to get up out of the track, but there is considerable sliding on the side-walls of the wheel.

Steel rollers tend to flatten some and to sink into a steel track or raceway. Even though the effect would not be noticeable to the naked eye, nevertheless, it is present and some friction is present even in the best of ball or roller bearings.

Rolling friction is always less than sliding friction as a comparison of Table 1 and 2 shows. The formula for rolling friction is identical to that for sliding friction, but the coefficients of friction are different.

	μ
Rubber tire on concrete	0.04
Steel ball bearings on steel	0.0025
Steel roller bearings on steel	0.003

(Table 2)

ANGLE OF REPOSE

If the component of weight parallel to an incline is just equal to the frictional force, (see Fig. 5) then the object will just slide down the incline at constant speed. The net force along the incline is zero since P = f:

$W \sin \theta r = \mu W \cos \theta r$

therefore:

$\mu = \tan \theta r$

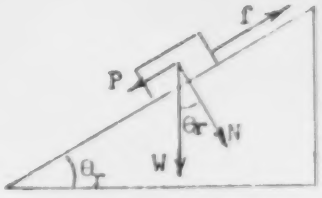


Fig 5

The coefficient of friction can be found by raising the incline until the object just slides downhill. The angle is called the angle of repose or the angle of uniform slip. As an example, kernels of grain or sand in a pile make a specific angle with the horizontal depending on the angle of repose or coefficient of friction between grains.

PART II

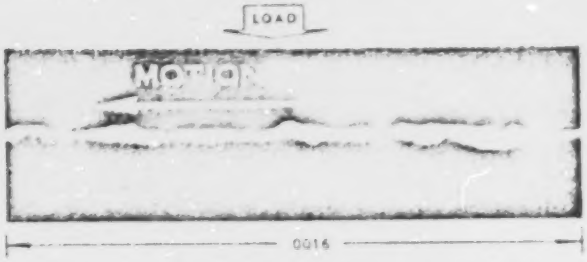
WHAT CAUSES FRICTION?

The forces that cause a tire to flex or flatten or those that are exerted on a wheel as it tries to roll up out of an indented raceway, have components in a backward direction. This backward component is a part of rolling friction. Another part of rolling friction, however, is attributed to sliding between surfaces in relative motion. The question, then, reduces to the cause of sliding friction.

If the surfaces are rough, the object is supported on stilts, peaks or prongs that hang down from it or stick up from the surface the object slides on. As the object begins to slide, the prongs bend over. After a high point has passed by, the prong then is released, perhaps vibrates a bit as it dissapates its stored up energy. It may permanently be bent or broken off. Friction can be attributed partially to the force required to bend these microscopic prongs.

A smooth surface has fewer prongs to bend and friction is reduced by smoothing the surfaces. A strange thing about friction, however, is that friction tends to increase after reaching a certain smoothness. Why does this happen? Before that question can be answered, some other discussion is necessary.

REAL CONTACT AREA



Magnified profile of highly polished surfaces shows how rough an apparently smooth metal surface can be and the small areas of actual contact between them. The finish of the two surfaces represented here is 8 microinches R M S. Magnification is 2000 times.

Figure 6 *

Figure 6 shows a highly magnified profile of very smooth surfaces. The four contact points have a real contact area that is a small fraction of the apparent area. The molecules of the upper surface are in real adhesive contact with those of the lower surface at these points. They are as close together at the four points of contact as they are inside the material of either object. Heat and electricity will conduct through these points (if the materials are good conductors). They are actually welded together at these points.

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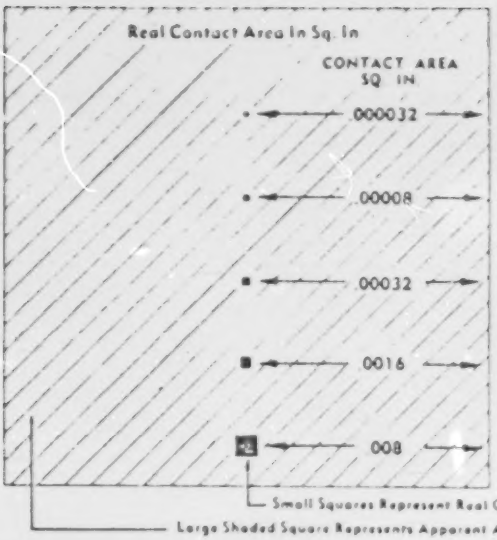

LOAD IN LBS	PRESSURE PSI		% of Area in Real Contact
	Theor'l	Real	
4.4	1.35	135,000	.001
11	3.4	136,000	.0025
44.1	13.5	135,000	.01
220.5	68	136,000	.05
1102	340	136,000	.25

Figure 7*

Electrical measurements of the actual contact area of two ground and lapped steel flats at various loads provides the data presented here. At each loading, true bearing pressure based on actual contact area is very high, approaching the compression yield strength of the material. It is surprisingly uniform despite the load imposed.

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The shaded portion of Figure 7 shows the apparent area of two steel flats in contact (1 in^2). The small dark squares show the real contact area as the normal force increases. The real contact area increases from 0.000032 in^2 to 0.008 in^2 as the normal force increases from 4.4 lb to 1102 lb. The percent of area in real contact increases from 0.001% to 0.25%.

Notice in Figure 7 that the apparent (theor'l) pressure (force divided by apparent area) increases from 1.35 lb/in^2 to 340 lb/in^2. The real pressure (force divided by real area) does not change and is very high, near the yield point of the metal.

Some quick calculations show that the real contact area increases in proportion to the normal force (see Fig. 7). Friction is, therefore, proportional to the real contact area even though it is unrelated to the apparent area. Real contact area is difficult to measure; electrical resistance is inversly proportional to area, so the contact area could be measured electrically if the materials are good conductors. Perhaps it's just as well that friction is determined as a function of the normal force.

Now to explain why friction increases as the surfaces become highly polished. When a smooth object slides over another, a force must break the adhesive (or cohesive) bonds at points of real contact. At rest, the object settles down and a few more points adhere. Once in motion, there is no time for settling. With fewer points in real contact at any instant, the coefficient of kinetic friction is less that that for static friction.

Surfaces with extreme smoothness have a greater ratio of real contact area to apparent area. There are more adhesive bonds to break as motion begins, so the frictional force becomes greater as surfaces become smoother. The real contact area may become a large percentage of the apparent area. In such cases, friction may be reduced by

reducing the apparent area. The bearing surface of jewelled bearings in watches is an example of such extreme smoothness.

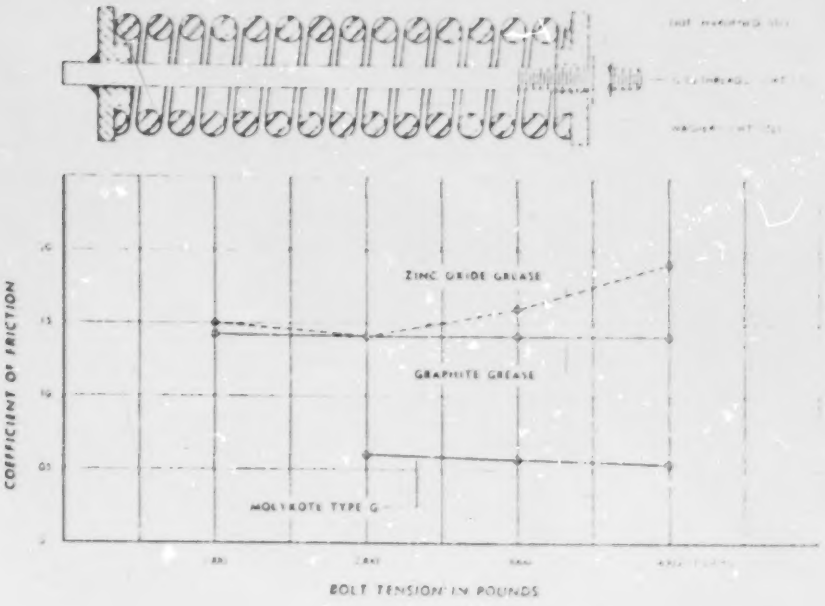

Figure 8*

Coefficient of friction for various solid lubricants calculated from data compiled with assembly shown above graph. A calibrated torque wrench was used and spring deflected to obtain bolt tension. Values for the molybdenum disulfide lubricant below 2000 lb tension were unobtainable because the wrench did not indicate the small torque values involved.

The coefficient of friction may change as higher pressure or higher temperatures are applied to the sliding surfaces. Figure 8 describes an experiment showing the change in the coefficient of friction as higher pressures are applied. The coefficient of friction of certain automobile tires such as "racing slicks" increases as the temperature goes up. The high sulfur content causes the tire surface to become sticky when heated. The nature of such changes is dependent on the nature of the materials themselves.

LUBRICATION

Fluid friction is a result of frictional force when a liquid flows past a solid surface and the flow between the molecules of the liquid itself. Since the molecules of a liquid are free to move, the use of liquids between sliding surfaces prevent most of the adhesion that is the source of friction. Fluid friction is much less pronounced than friction between solids (see Table 1). Naturally, there are great differences in lubricants.

Additional information and problem examples may be found in your text.

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PROBLEMS

Module M 6 FRICTION

1. Explain the difference between real contact area and apparent area between sliding surfaces and the effect of each on friction.

2. Explain the difference among static friction, limiting friction and kinetic friction between sliding surfaces.

3. Explain how the angle of repose can be used to find the coefficient of friction between sliding surfaces.

4. Explain how the normal force acting on sliding surfaces on an incline changes as the angle of incline changes from 0° to 90°. Show a graph of this relationship.

5. A steel roller in a hot-mix plant rotates in a lubricated bronze bushing. The coefficient of friction is 0.10. A V-belt exerts an upward pull of 195 lb on the bushing. The bushing also supports 11 lb of the roller's weight. Find the frictional force on the shaft if it rolls 15° from top dead center before spinning begins. See Figure 4 in the information sheets. Assume V-belt tension doesn't increase as it rolls.

6. A man is standing on a roof which has a 25° incline. What must be the minimum coefficient of limiting friction between the man's shoes and the roof to prevent slippage? If the coefficient of friction is 0.33, what maximum angle of incline could the roof have without slippage?

7. In tightening a bolt, sliding occurs between the threads and between the head of the bolt and the washer. Correct tension, if it is required, is achieved with a torque wrench. If the tension in a ½ in bolt is 1000 lb, what is the friction (limiting) if the coefficient is 0.75? What happens to the tension and friction as the bolt is tightened?

8. A maintenance truck pulling a trailer with a load of bridge planking on it is climbing a hill with a 12° incline. If the trailer and the load weigh 5 ton, and the coefficient of rolling friction is 0.06, find the force of friction on the trailer and the pull the truck must exert to maintain low constant speed up the hill. Neglect air resistance.

9. A brake on a derrick consists of a disk rigidly attached to an axle. Brake shoes press against each side of the disk. A frictional force of 425 lb on the disk will prevent the derrick load from lowering. Will a force of 490 lb on each shoe hold the load if the limiting coefficient of friction is 0.4?

PROBLEMS CONTINUED

10. A screw pick is used to lift a 1200 lb weight vertically. If the coefficient of limiting friction is 0.68, find the limiting frictional force between the threads. What is the kinetic friction if the kinetic coefficient is 0.48?

11. A "Mechanical Mountain Road" is a device consisting of a trailer with an electric brake and can simulate the forces on any car for any road grade. If the device is used to simulate the forces on a 4000 lb automobile going up a 15° incline, find the component of the car's weight down the incline; the normal component of the weight, the frictional force, and the total force the device must exert on the car. The test is run on level ground at low speeds so air friction can be neglected. The coefficient of friction between tires and road is 0.06.

ANSWER KEYS (PROBLEMS)

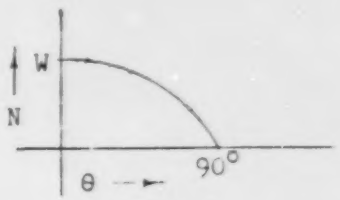
Module M 6 FRICTION

1. See information sheet. Friction is independent of the apparent area.

2. Static friction varies from zero to the limiting friction depending on the applied force. Kinetic friction is the average value after motion begins.

3. Raise incline until slippage begins, note angle: $\mu = \tan \theta r$

4. $N = W \cos \theta$



5. 19.9 lb

6. 0.47, 18.3°

7. 750 lb, both increase

8. 587 lb, 2670 lb

9. No, friction is 196 lb on each shoe, 392 lb on disk.

10. 816 lb, 576 lb

11. 1035 lb, 3863 lb, 231 lb, 1267 lb

EXPERIMENTS

Module M 6 FRICTION

PURPOSE: The pupose of this experiment is to study friction and some of the factors that influence friction. Friction on an inclined plane is also studied.

CAUTIONS:

1. Read all the instructions before handling any of the equipment.
2. Keep the plastic foam keeper in place on the Harvard trip balance when it is not being used.
3. The balance scale is a delicate instrument. When you weigh the wooden block, take it to the balance scale instead of carrying the balance scale to your lab station. It receives less wear and tear this way.
4. Never interfere with an experiment someone else is performing or with the equipment they are using. Horseplay is never appropriate in a laboratory situation.
5. Observe all cautions listed in the procedure section below.

EQUIPMENT: Check to see if all the following equipment is available before you start. Ask your instructor if you have any questions about the equipment.

1. Inclined Plane (Sargent-Welch #0809)
2. Friction Block (Sargent-Welch #0977)
3. String
4. Weight hanger
5. Slotted weight set
6. Balance scale and weights available in classroom.

INFORMATION: Friction always opposes motion or the tendency of motion. On an incline, friction is a force downward when an object is being pulled up the incline. When the object moves down the incline, friction is upward along the incline.

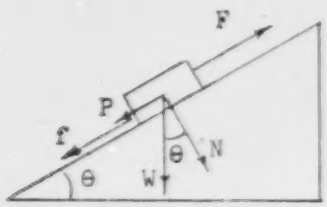


Fig 1

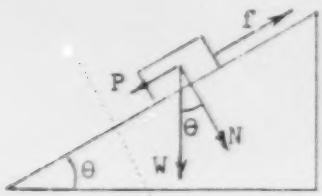


Fig 2

Figure 1 shows the first case where a force (F) pulls the object upward. It must overcome the effects of force P (component of the weight down the incline, $P = W \sin \theta$) and friction (f). Figure 2 shows an object moving down the incline. Notice that friction is upward in this case. The object will move only if P is larger than f.

The frictional force (f) is equal to the normal force (N) (the perpendicular component of the weight) times the coefficient of friction (μ).

$$f = \mu N$$

The normal force can be found by the formula: $N = W \cos \theta$.

For further information, see your text or the information sheet in this booklet.

PROCEDURE:

1. Place the inclined plane (set on 0°) on a table or lab bench so the pulley hangs over the edge.

NOTE: Exact leveling of the surface is unnecessary.

2. Weigh the friction block on the balance scale. Record on the data sheet.

3. Attach the wooden friction block to one end of the string on the hook provided and attach the other end of the string to the weight hanger.

4. Place the block on the surface of the inclined plane near the center and let the weight hanger hang over the edge of the table with the string in the pulley.

NOTE: The string between the friction block and the pulley should be parallel to the plane. Adjust by raising or lowering the pulley.

5. Hang slotted weights on the hanger to find the force required to just move the friction block along the plane. Be sure to include the weight of the hanger (50 g). The weight on the hanger and the hanger itself is equal to the frictional force on the block. Record on the data sheet.

NOTE: The block should just creep when you tap the inclined plane surface lightly with your fingernail or pencil.

6. Add 200 g to the weight of the block by laying slotted weights on top.

7. Repeat step 5 after resetting the block in the same place on the incline. The block should creep at about the same rate with the same amount of tapping. Record the data.

8. Repeat steps 6 and 7 with 400 g, 600 g, and 800 g on the block. Record the data.

9. Calculate the coefficient of friction for each line, record in the proper place and find the average.

10. Raise the incline to find the angle of repose. The block without weights should just creep down the incline by tapping as before. Record the angle, calculate the coefficient of friction and compare with step 9 by calculating the percentage difference.

11. Set the angle of the incline between 25° and 35°. Record.

12. Calculate the force (F) required to just make the block creep up the incline. Refer to Figure 1 and the information that accompanies it. (Page) Record.

13. Measure the force (F) required to just make the block creep (by tapping) up the incline.

14. Compare the calculated and measured value of the force F. (Find the percentage difference.)

15. Calculate the percentage ratio of the area of the block along the edge to the area of the block laying flat.

16. Adjust the angle of incline to 0°, lay the block on edge and adjust string so it is parallel to the plane. Measure the force of friction by hanging slotted weights on the hanger.

17. Compare the frictional force measured on edge to that measured in step 5 by calculating the percentage ratio.

18. The results of step 15 and 16 should show that friction is independent of the apparent area, even though friction may be slightly different. What do you attribute the difference to?

Applied Physics Module

SOUTHEAST COMMUNITY COLLEGE—Milford Campus Milford, Nebr. 68405

Module: M 7

Title: The Laws of Motion

Module Contents:
1. Force causes change in motion
2. Inertia
3. Newton's three laws of motion
4. Mass and weight units

Program: This module has been especially prepared for students in:

1. Surveying and Drafting
2. Architectural Technology
3. Building Construction Technology

Purpose: The purpose of this module is to extend the study of motion (module M 5) to include the cause of changes in motion. It is the change in motion and the forces involved that you as a technician must understand and control if you want matter to interact to your advantage. Applications are included in the problem sets and are much the same as those in module M 5. The study of Newton's laws of motion is prerequisite for modules on work, energy, power, and others that follow.

Producer: Gene Waring

Date Produced: September, 1976

This project was performed pursuant to a grant from the State Board of Vocational Education through the Nebraska Research Coordinating Unit using federal funds made available under Public Law 90-576 part C, Research.

STUDENT INSTRUCTIONS

Module M 7 THE LAWS OF MOTION

OBJECTIVES

When you have satisfactorily completed this unit, you will be able to:

1. Define inertia.
2. State Newton's three laws of motion.
3. Distinguish between mass and weight by defining each, by stating the units of each in the British, SI and cgs measuring systems and by stating the relationship between the two quantities.
4. State the difference between absolute and gravitational measuring systems.
5. Show an understanding of Newton's third law by citing several examples of action-reaction pairs of forces applied to various pairs of objects.
6. Show that any pair of action-reaction forces do not cancel by describing a pair of objects, the direction of the forces on them and which object each force acts on.
7. Solve various problems involving Newton's second law.
8. Solve various problems involving Newton's second law and the laws of motion described in module M 5.
9. Carry all units and dimensions through the entire solution of problems.

In order to satisfactorily complete this module, you must pass a test consisting of true-false, multiple choice and problem type questions based on the objectives listed above with a grade of at least 80%.

SELF-EVALUATION TEST

Perhaps you have had previous experience with the study of motion. You may feel that your experience will enable you to perform most of the tasks listed in the objectives section above. A self-evaluation test (or sample test) is included in this booklet (pink paper, page 6) along with an answer key. You can evaluate your previous knowledge of the subject by taking this test (under normal test conditions) before you perform any of the learning activities listed below.

The results of this test is an indication of your knowledge. If you can answer all questions correctly, you may not need additional study. However, you should proceed with the learning activities if you can't answer all questions, correctly. The answer key page (pink paper, page 7) directs you to various learning activities.

Before you take the instructor-graded test (post-test), read the "test" section at the end of these instruction pages (white paper, page 5).

LEARNING ACTIVITIES

The following list of activities is designed to help you achieve the objectives of this module. You are not required to complete all of the activities. They are intended to supplement your previous knowledge of the subject. If you wish, your instructor will recommend the learning activities you should complete.

I. Reading: The chapters, sections and page numbers are given for several textbooks. You may select your own textbook. As you read, keep the list of objectives handy. Write down on separate paper a list of the definitions, laws, principles, formulas, etc. that the objectives refer to. This list will be very useful as an aid to learning them.

A. Introductory Applied Physics, Harris, N.C., Hemmerling, E.M., McGraw-Hill, 3rd ed., 1972. Read chapter 3, section 3.16-3.22, pages 66-83.

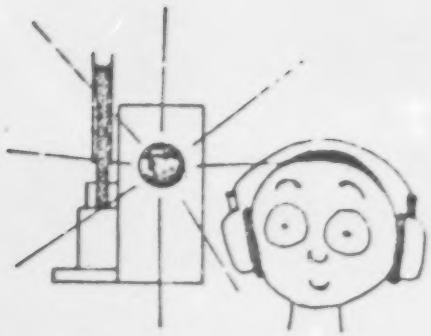
B. Elements of Physics, Smith A.W., Cooper, J.N., McGraw-Hill, 8th ed., 1972. Read chapter 6, sections 6.1-6.8, pages 63-71. Omit section 6.9.

C. Physics for Career Education, Ewen, D., Nelson, R., Schurter, N., McFadden, L., Prentice-Hall Inc., 1st ed., 1974. Read chapter 6, sections 6.1-6.7, pages 54-67. Omit section 6.8.

D. Physics for Technology, Betts, J., Reston Publishing Co. Inc., 1st ed., 1976. Read chapter 4, sections 4.1-4.6, pages 43-55. Omit section 4.7.

E. Modern Technical Physics, Beiser, A., Cummings Publishing Co. Inc. 1st ed., 1966. Read chapter 5, sections 5.1-5.8, pages 62-77.

II. Listening/Viewing: The following single concept film loops (8 mm) are available in the Learning Resource Center (LRC). There is a brief training session given by the LRC staff to familiarize you with the film loop projector (Technicolor or Viewlex 702) and must precede the viewing of the films. Ask the LRC personnel about this training.



A. Newton's Laws of Motion, (BFA Ealing 80-4187)

B. Inertia I, (BFA Ealing ISBN 0-03-080162)

C. Inertia II, (BFA-Ealing ISBN 0-03-080163)

D. Newton's First and Second Laws, (BFA Ealing 80-2736)

E. Newton's Third Law, (BFA Ealing 80-2744)

F. Inertial Forces, (BFA Ealing 80-2132)

III. Solving Problems: Solve the problems in the problem set in this booklet. They are printed on ivory paper (page 8). Answers are given for each problem. Solve as many of them as you feel are necessary to gain competence in solving Newton's Law problems. The problems from number five on are applied to your technology.

IV. Solving Problems (Optional): Solve some of the problems at the end of the reading set in your textbook. These are for additional practice if you feel it is needed and are mostly general interest problems.

V. Performing Laboratory Experiments: There are two experiments in this module. They will give you experience involving the laws of motion.

Read the laboratory instructions in this booklet (yellow paper, and pay particular attention to the cautions given). Obtain a laboratory data sheet (M-7) and the equipment from the instructor. Keep this booklet open to the instruction pages and proceed step by step with the experiment.

TEST

You may proceed with the test at any stage of your study of this module; obtain a copy of the test, answer all questions, and return it to your instructor.

A grade of 80% is required for satisfactory completion of the module. A grade lower than 80% will require that you repeat the test. You must show evidence of further study before you repeat it, however. (Hand in your papers on problem solving, lab reports, etc.)

Every test you take on this module will be averaged to determine your module grade. Don't take the test until you have adequately prepared yourself to meet the requirements listed in the objectives section. Instead, go to the learning activities.

SELF-EVALUATION TEST

Module M 7 THE LAWS OF MOTION

Read each question carefully and decide which one of the answers is best. Notice what letter your choice is. Then, on separate paper, write the problem number followed by the letter you chose. Take the test under normal test conditions; without help from other people and without references. The answer key is on the following page.

T - F 1. The inertia of an automobile increases as its velocity increases.

T - F 2. According to Newton's third law, a single externally applied force cannot act on an object.

T - F 3. The kilogram is the unit of mass in the MKS (SI) measuring system.

T - F 4. The slug has units that may be expressed as lb/ft·s in British fundamental units ($F = ma$).

T - F 5. A net force of 5 lb acting on a 1.25 slug mass will accelerate at 4 ft/s^2.

6. A weight of a large torque wrench is 7 lb. Its mass in slugs is:

a) 0.22 c) 0.71
b) 224 d) cannot be calculated

7. A certain net force gives an 8 kg lead ball an acceleration of 3 m/s^2. The same net force would give a 24 kg ball an acceleration in m/s^2 of:

a) 24 c) 12
b) 1 d) 48

8. When an object is accelerated, you know for sure that:

a) its velocity increases c) a net force acts on it
b) its velocity decreases d) it falls freely

9. A 3600 lb automobile is traveling 45 mi/h. How much distance will it take to come to a stop if a braking force of 875 lb is applied?

10. An elevator with its load weighs 5000 lb. What is the maximum upward acceleration it can have if the supporting cables can safely withstand no more than 7500 lb of tension?

ANSWER KEY TO THE SELF-EVALUATION TEST

Module M 7 THE LAWS OF MOTION

Question-Answer	If you missed this question, you are directed to these learning activities
1. F	I. Reading or V. Experiment 2
2. F	I. Reading
3. T	I. Reading or II. Listening/Viewing
4. F	I. Reading or III. Solving Problems
5. T	III. Solving Problems
6. a	III. Solving Problems
7. b	III. Solving Problems or V. Experiment 1
8. c	I. Reading
9. 280 ft	III. Solving Problems or V. Experiments
10. 16 ft/s^2	III. Solving Problems or V. Experiments

PROBLEMS

Module M 7 THE LAWS OF MOTION

1. Compare an action-reaction pair of forces with a resultant-equilibrant pair. Both pairs are equal and opposite. The latter pair cancels. Why doesn't an action-reaction pair cancel?

2. Whiplash is a serious neck injury incurred by a driver or passenger in a stopped car which is struck from behind. What causes such injuries?

3. If a force which is equal to the weight of an object is applied to the object, what will be the acceleration?

4. Express the units of mass in fundamental British units.

5. Express the units of force in fundamental MKS and cgs units.

6. What happens to a person standing on a bus or sitting in a car when (a) there is a large forward acceleration, and (b) when the brakes are suddenly applied?

7. Discuss the physics involved in each of the following:

   a) Removing mud or snow from boots by kicking against a rock.
   b) Removing water droplets from hands by the whipping action of your wrists.
   c) Forcing a hammer head onto a handle by jamming the handle against a concrete step.
   d) Running up to a patch of ice then sliding.

8. A crane is raising a pre-stressed concrete beam to the 4th floor of a building under construction. It momentarily accelerates the load at 3 m/s^2. If the load has a mass of 25 500 kg, what is the net force on it?

9. A truck pulls a 12 500 lb trailer, which is carrying concrete culvert pieces. If the net force on the trailer is 825 lb, what is its acceleration?

10. A surveyor, carrying a 45 lb pack of instruments, enters an elevator to a mine shaft. The elevator car accelerates and decelerates at 8.3 ft/s^2. What force will he have to apply to support the pack as the elevator starts upward? As the elevator moves upward at constant speed of 6 ft/s? As the elevator stops at the top of the mine shaft?

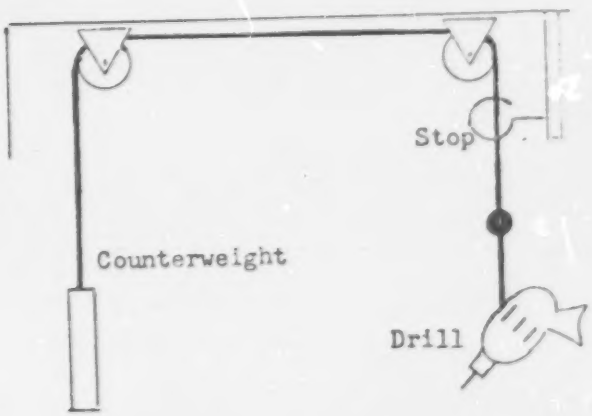
11. A road crew returning to the construction yards from a job, was traveling 55 mi/h in a 4600 lb van. As the driver came to a railroad crossing he noticed a train approaching. He applied the brakes at a point 420 ft from the crossing. If the braking force (assumed constant) was 1170 lb, was he able to avoid a collision?

12. An air tool operator accidentally drops a 1 lb wrench from a 40 ft bridge structure. A 6 ft tall construction worker (not obeying all safety rules) was standing underneath. The wrench made a dent in the worker's metal hard hat, forced the hat downward on his head, and caused his head to move downward slightly. What average force was exerted if the wrench came momentarily to a stop in a total distance of 2.5 in?

13. A 2070 kg culvert flared-end section, is being lowered by a crane. A maximum braking force of 3500 N can be applied by the operator. What minimum distance is required to stop the end section if it is being lowered at a speed of 1 m/s?

14. A trailer and its load of pre-stressed concrete bridge piling, weighing 10 000 lb, is being pulled by a truck. As the truck begins to move, it accelerates at 3.4 ft/s^2. What force does the truck exert on the trailer hitch if the coefficient of friction between the trailer's tires and road is 0.06?

15. A crane is used to lift a 2070 lb culvert pipe onto a trailer. As the pipe begins to clear the ground, the total tension in the cable is 2185 lb. What is the acceleration at that instant?

16. 

At one station in a plant that manufactures pre-fabricated walls for storage buildings, a drill is used to make bolt holes.

The drill is attached to a small cable that runs over a set of pulleys to a counterweight in a remote corner. The drill is up out of the way when not in use. The counterweight weighs 5 lb, the drill is 3 lb, and there is 1.25 lb of friction in the pulley. Find the acceleration of the drill-counterweight system neglecting the weight of the cable. The drill is restricted from moving more than 3 ft upward. How much time is required for it to move that distance after being released? With what speed does it strike the restriction?

17. A nail is being driven into a 2 x 10 in floor joist. The hammer has a mass of 0.35 kg, and is moving at a speed of 9 m/s just before contact with the nail. Assuming the acceleration is constant, find the average force exerted on the hammer if it comes to a stop while driving the nail 1 cm. What is the force on the nail?

18. Answer the same question as in problem 17; if the hammer (more realistically) rebounds with a speed (just after contact is broken) of 3 m/s.

19. The ram and its cap on a McKiernan-Terry diesel pile driver weighs 3680 lb. The ram hits the piling at a speed of 19.6 ft/s, and rebounds with a speed of 12.6 ft/s while driving the piling 3 in. What is the average force on the ram? On the piling? Assuming the force is constant, how much time are the ram and piling in contact?

ANSWER KEYS (PROBLEMS)

Module M 7 THE LAWS OF MOTION

1. Resultant and equilibrant act on same object, action-reaction don't.

2. Neck, bones, and muscles cannot exert necessary force to accelerate head. Inertia causes head to be left behind; twisting neck, causing injury.

3. 32 ft/s^2

4. $lb \cdot s^2/ft$

5. $kg \cdot m/s^2$, $g \cdot cm/s^2$

6. See definition of inertia.

7. Boot, hand, and hammer handle suddenly stop; but, mud, snow, droplets, and hammer head keep going. Inertia causes objects to continue moving.

8. 76 500 N

9. 2.11 ft/s^2

10. 56.8 lb, 45 lb, 33.3 lb

11. Yes, stopped in 400 ft.

12. 163 lb

13. 30 cm

14. 1660 lb

15. 1.78 ft/s^2

16. 3 ft/s^2, 1.4 s, 4.2 ft/s

17. -1420N, +1420N, NOTE: Force and acceleration are not constant.

18. -1260N, +1260N, NOTE: Force and acceleration are not constant.

19. -51 800 lb, + 51 800 lb, 0.0333s

EXPERIMENTS

Module M 7 THE LAWS OF MOTION

PURPOSE: The purpose of these experiments is to (1) to study Newton's Second Law of Motion on an air track. You will make these runs with the spark recorder; (2) to use an inertial balance to see that mass can be measured independently of the force of gravity.

CAUTIONS:

1. Read all of the instructions before handling any of the equipment.
2. The Basic Spark Source can cause deep painful burns as well as shock. Read and follow the instructions carefully.
3. Observe all cautions in the procedure section of these instructions.
4. Never interfere with an experiment someone else is performing or with the equipment they are using. Horseplay is never appropriate in a laboratory situation.

EXPERIMENT I

INFORMATION: A linear air track is used in the first experiment. It is a simple device which allows you to observe motion in which there is almost negligible friction. Glides are supported so they "float" and move on a cushion of air produced by blowing air with a vacuum cleaner out of small holes on the track. The viscosity of the thin layer of air between the glider and track is the only source of friction

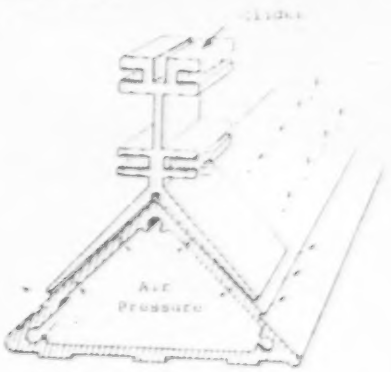
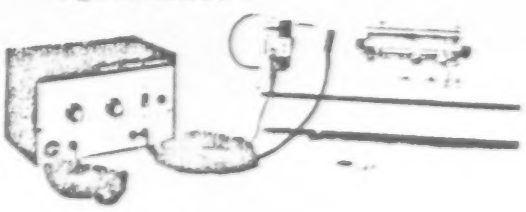


Figure 1. Track Cross Section
By permission: The Ealing Corporation

The air track is a precision device. Distances along the track can be measured to the nearest millimeter. The timing measurements needed for studying motion are made with a timing device that generates high voltage pulses at regular intervals. The resulting spark holes recorded on spark paper make a record of the position of the glides each time without affecting the motion of the glider. You should view film A, (See Listening/Viewing, page 4) before proceeding with the experiment.

EQUIPMENT:



1. Student 1.2 m air track (Ealing 33-1512)
2. Two stage blower - 115 v (Ealing 33-0167)
3. Various blower hoses, couplings, tees, manifolds, etc.
4. Basic spark source - 60 Hz (Ealing 33-2403)
5. Spark tape (Faling 33-0274)

Figure 2. Basic Spark Source
By permission: The Ealing Corporation

Check to see that all equipment is available before you start. Ask your instructor if you have any questions about the equipment. Obtain a data sheet from the instructor.

PROCEDURE:

CAUTION: Do not plug in the basic spark sourc until you are ready to use it. See step 14 below. Shocks from this spark source can burn small, deep, and very painful holes in your skin. Other injuries can occur as you react to the shock. BE EXTREMELY CAREFUL NOT TO TOUCH THE SPARKING WIRE when the spark source is attached.

CAUTION: Be careful not to drop the glides. Dropping them from even a few inches height will probably ruin them. To avoid damaging surfaces, do not slide the glides on the track with the air supply shut off.

1. Attach the air hose from the vacuum cleaner to the air track.

CAUTION: Keep the air hose on the back or side of the table so it will not be bumped. It could drag the air track off the table.

2. Plug in the air supply (vacuum cleaner) and turn it on. If only one track is being used, remove one rubber stopper from the manifold on top of the air supply. The entire supply is not needed for one track.

LEVEL THE AIR TRACK

3. Remove all gliders except one. Place one glider near the center of the track. If the track is level, the glider will not accelerate in either direction. Turn the adjusting screw knob on the air supply end of the track. Note: Slight adjustments make large changes in the glider's motion.

CAUTION: Do not bump or jar the track once it is leveled. Small irregularities in the table top will have a large effect on the gliders motion if the track is moved. Naturally, you should also avoid bumping or jarring the table for the same reason.

4. Shut off the blower during set-up time.

5. Insert a strip of spark paper in the groove on the back side of the air track. A 120 cm length is sufficient.

6. If a transfer wire is not attached to the nylon post on one end of the gliders, wrap one turn of copper wire around the post and tighten. Bend the wire in the shape shown in Figure 3.

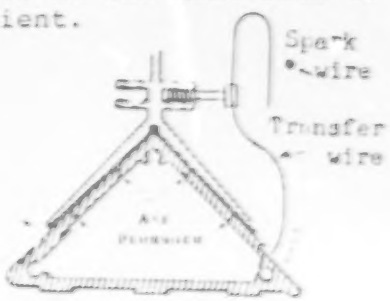


Figure 3. The Transfer Wire
By permission: The Ealing Corporation

NOTE: The transfer wire is vertical, near the sparking wire so it will not matter if the sparking wire sags a little. The bottom end of the transfer wire is placed near the upper edge of the spark paper. By bending the wire downward, more than one run can be made on one strip of paper.